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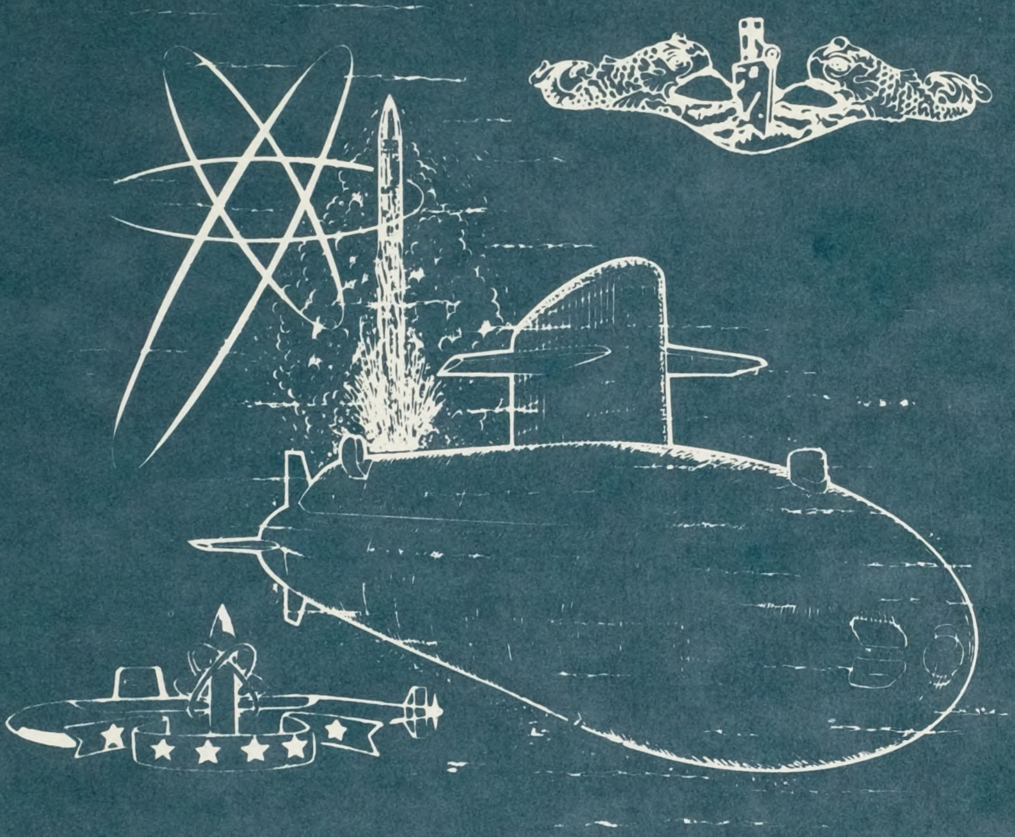

VOL. 1

# FIRE CONTROL TECHNICIAN B 3 & 2

NAVAL EDUCATION AND TRAINING COMMAND

RATE TRAINING MANUAL
AND NON-RESIDENT CAREER COURSE

NAVEDTRA 10211-B1

Although the words "he", "him", and "his", are used sparingly in this manual to enhance communication, they are not intended to be gender driven nor to affront or discriminate against anyone reading *Fire Control Technician B 3 & 2, Vol 1,* NAVEDTRA 10211-B1.

# PREFACE

This rate training manual and nonresident career course (RTM/NRCC) form a self-study package for Fire Control technician B personnel who are fulfilling the requirements of their rating at the second or third class level.

This RTM relates directly to the FTB Occupational Standards and is based on the POSEIDON Weapon System. (Volume 2, a separate publication is also based on POSEIDON.) The NRCC provides one of the normal ways to satisfy the requirements for completing the RTM.

Browse through this entire package, and become at least roughly familiar with the contents before you begin serious study. The introduction at the beginning of the NRCC gives you essential information for completing and getting credit for the course. Note the LEARNING OBJECTIVES in the NRCC assignments, and use them as individual goals as you study. By becoming familiar with the entire package before you start, you ensure that your study experience will be more meaningful and efficient. Good luck.

This training package was prepared by the Naval Education and Training Program Development Center, Pensacola, Florida, for the Chief of Naval Education and Training. Special credit is given to the Strategic Systems Project Office, Washington, D.C., the Naval Guided Missile Schools, Dam Neck, Virginia Beach, Virginia; and the FBM Training Center, Charleston, South Carolina.

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# THE UNITED STATES NAVY

## GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

## WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

## THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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# NOTICE

The original (1979) editions of this rate training manual and nonresident career course were based on the POLARIS missile system, now obsolete. This new minor revision has deleted the subject matter that pertained only to POLARIS. The remaining material is applicable to systems currently operational.

Gaps appear in the numbering of pages and questions where the POLARIS material was deleted from the original print. The INDEX still lists subjects that have been deleted from this current edition. By deleting material and using original manuscript for the remaining parts, the cost of producing this edition has been reduced.

Persons who completed the original edition, *Fire Control Technician B 3 & 2,* Volume 1 NAVEDTRA 10211-B, should not be required to complete this edition of the NRCC. Naval Reservists who completed the original should not receive retirement credit for this edition.

CHAPTERS 1, 2, AND 3 (PAGES 2 THROUGH 37) HAVE BEEN DELETED FROM THIS EDITION.

## CHAPTER 4

# ANALOG ELECTROMECHANICAL DATA SENSORS

It takes a great deal of information to solve the weapon control problem. This information must be transmitted between equipment units located some distances apart. For example, own ship heading, speed, and position information are sent from the navigation system to fire control, which in turn transmits velocity-to-be-gained and initial velocity information plus the alignment and erection angles to the missile. The nature of the weapon control problem and of the data involved demands accurate data sensors and complex transmission systems.

### MANIPULATION OF DATA

Before we cover data sensors we will briefly discuss the concept of converting data into a different but related form. The related form is referred to as an analog or scaled value of the original quantity. The simple transmission circuit in figure 4-1 indicates "yes-no" type information, which tells only if and when an event takes place. But many fire control quantities have a numerical value that must be transmitted in order to describe the quantity. This numerical value indicates the amount or position of the quantity along a scale in a "set" or series of units.

A ship depth of 100 feet indicates that the ship is so many, (100), units, (feet), below sea level. This unit of measure is not convenient to use directly as a signal in a transmission system. A foot is a linear distance and would require a linear movement of that length to be used directly as a signal. If we changed the unit of measure to volts, ship depth could be defined in an electrical circuit as 100 volts. This is not improper as long as the units (feet/volt) represent an equal distance and a change in depth would result in an equal or proportional change in the number of volts. If the ratio of one volt per foot is too large, we can change the ratio. We shift scale in many types of measure; miles to yards and degrees to minutes of arc are some examples. Thus we can make one volt equal to 10 or 20 feet. As long as the ratio between units is constant throughout their operational range, we are not incorrect.

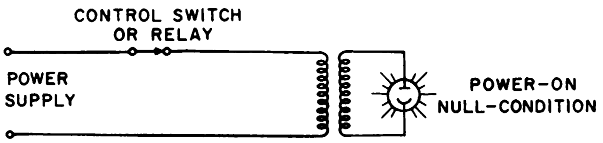

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Figure 4-1.—Simplified Transmission Circuits.

In figure 4-1, if the basic circuit were changed so that a measurement of 5 feet could be represented by a voltage and the lamp replaced by a voltage reading device, graduated in distance, this circuit would be an analog transmission circuit.

The analog of a quantity can be defined in many types of measure. Hence we can transmit quantities such as depth, latitude, and velocity as voltages in an electrical circuit, motion in a mechanical system, or pressure in a pneumatic system. This is a basic concept in analog data transmission systems. We discussed this briefly in our coverage of basic mechanisms.

Some quantities can be described completely by their numerical value. This type quantity is referred to as a scalar quantity and the direction of the quantity is not essential to its definition. Speed is an example of a scalar quantity, since it is not related to a direction and is defined solely by its magnitude. But if we resolve ship speed into its northward and eastward components we obtain ship velocities. These velocities are in a definite direction. This type quantity is referred to as a vector quantity and it takes two separate units of measure to define it. One unit defines the magnitude of the quantity and the other unit its direction. Some examples of scalar quantities are length, speed, power, mass, and time. Some examples of vector quantities are displacement, velocity, acceleration, force, torque, and weight.

The data sensors in a system that is transmitting a scalar quantity are position sensing devices which indicate the magnitude of the quantity by measuring a displacement from a reference point. Normally, the reference point is the zero position of the data sensor. The displacement is measured in the same units of measure used to define the magnitude of the scalar quantity. In most systems a vector quantity is transmitted as two scalar quantities. One scalar quantity defines the magnitude and the other scalar quantity the direction of the vector quantity.

## DATA SENSORS

The majority of data sensors are analog type devices in that they simulate the original quantity in a continuous scale system of measure. The value of the sensed quantity is detected by variations from a preset reference condition or position of the data sensor. The data sensor constructs an analog of the original quantity by generating a signal that is proportional to the amount and direction of offset from the reference. The input signal to a data sensor may be mechanical and the output electrical or vice versa.

The more common data sensors and their applications are covered in Synchro, Servo, and Gyro Fundamentals, NAVEDTRA 10105. It is strongly recommended that you study this basic manual. Particular attention should be given to the methods used to zero the data sensors. The data sensor's reference condition or position is established by zeroing it.

## SYNCHROS

The term "synchro" is an abbreviation of the word "synchronous" and is the name given to a variety of rotary, electromechanical, positioning-sensing devices. Synchros are designed to provide a physical measure of shaft position as the result of an electrical input, or conversely, to provide an electrical output that is a function of its shaft position.

Synchros are used extensively in the weapons, navigation, and control systems of surface ships, submarines, and aircraft. They are used in applications which vary from a simple torque indicating system to a complex computing system.

In the simple synchro torque indicating system, a synchro unit called a transmitter is connected electrically to another similar unit called a receiver. When the rotor of the transmitter unit is moved, the rotor of the receiver moves the same amount.

Synchros are widely used in remote indicating systems. They provide the means for transmitting data to one or more remotely located indicators. These indicators (receivers) provide such data as roll, pitch, heading, speed, helm position and rudder position along with much other information.

In addition to supplying data by positioning dials and pointers, synchros are used in many other applications such as opening and closing electrical contacts, and positioning hydraulic pilot valves. Further, synchros are used in many control applications. For example, a control synchro unit may be used to supply the control signals to servosystems which move such loads as radar antennas, missile launchers, gun turrets, aircraft and ship rudders, and many others.

### Construction

A synchro resembles a small electrical motor in size and appearance but operates like a variable transformer. Each synchro contains a rotor, similar in appearance to an armature, and a stator, which corresponds to the field in a motor as shown in figure 4-2. The synchro is

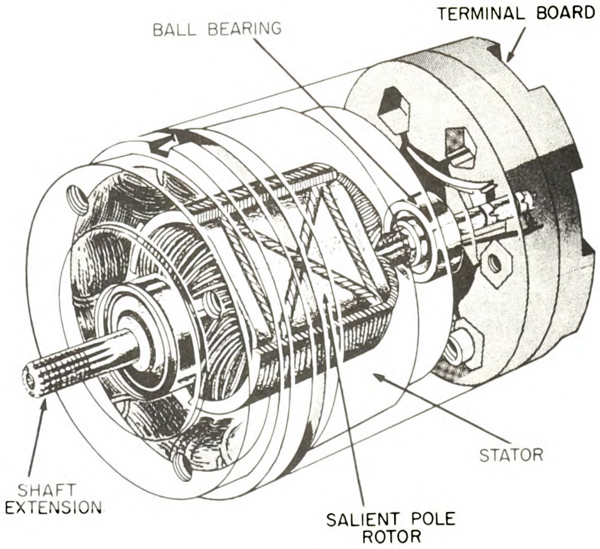

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Figure 4-2.—Phantom View of a Synchro.

usually composed of a three-winding, Y-connected stator, encased in a cylindrical metal shield and a rotor with one winding. The rotor is mounted within the stator and is free to turn within the stator windings. As the one-winding rotor of a synchro is rotated, the amount of coupling in the three stator windings is varied, producing a variable voltage output that represents the amount and direction of displacement of the rotor from the stator.

The rotor (which is usually the primary winding of the synchro unit) is wound on sheet-steel laminations stacked together and securely mounted on a shaft. To enable the excitation voltage to be applied to this winding, two sliprings are mounted on one end of the shaft and insulated from it. An insulated terminal board, mounted on one end of the cylindrical frame, houses the brushes which ride on the sliprings. This terminal board and another insulated block that is mounted on the other end of the synchro frame contain low friction ballbearings.

### Classification

The two general classifications of synchros are torque and control. Torque synchros are used in lightly loaded synchro systems, whereas heavily loaded systems are control synchros. Torque synchros provide a mechanical output, control synchros provide an electrical output.

Torque synchros are used for light loads such as positioning dials, pointers, and similar indicators. A torque transmitter (TX) and a torque receiver (TR) make up a simple torque synchro system. The TX and TR are electrically identical, however, they do differ slightly physically. The TR has an inertial damper (similar to a flywheel) mounted on its shaft to reduce oscillations.

Control synchros are used in servosystems which position heavy loads such as radar antennas, missile launchers, and many others. A control transmitter (CX) and a control transformer (CT) make up a simple synchro control system. The CX is identical to the TX but produces less torque, and has greater accuracy. The CT supplies an electrical signal output from its rotor corresponding to the shaft position of the CX to which it is connected and is constructed somewhat differently from the other units mentioned previously.

Synchros may also be classified according to operating frequency. If two synchros of equal power handling ability are built (one designed for 60 Hz excitation and one designed for 400 Hz excitation) the one designed for the higher frequency may be made physically smaller. This miniaturization is limited only by manufacturing and design capabilities.

The physical characteristics and construction of 60 Hz synchros and 400 Hz synchros are similar. Lines of flux produced by the 400 Hz excitation are much more concentrated than those produced by 60 Hz excitation; therefore, the core size of the 400 Hz synchro can be made smaller. If the number of turns in the rotor winding is reduced, the number of turns in the stator winding must be reduced accordingly. Because the transformation ratio is not changed, the power output of the smaller 400 Hz synchro can be the same as the power output of a 60 Hz synchro.

### Synchro Principles

The conventional synchro unit is essentially a transformer with a rotatable primary winding and three secondary windings spaced 120 degrees apart as shown in figure 4-3.

When an a-c voltage is applied to the rotor (primary) winding of a synchro, a magnetic field is set up around the soft iron, laminated core of the rotor. This magnetic field induces voltages into the three Y-connected stator (secondary) windings.

The angular displacement of the rotor from the reference position varies the induced voltage in each stator winding by an amount equal to the cosine of the angle of displacement. Therefore, as the position of the rotor is changed in relation to the stator, the voltage induced in each stator winding varies as a function of the angular displacement of the rotor from the stator.

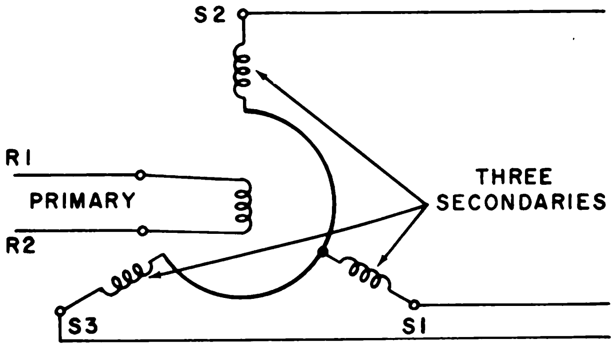

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Figure 4-3.—Transformer With One Primary Winding and Three Secondary Windings.

If the position of the rotor is parallel to one of the stator windings, maximum voltage will be induced into that winding. The voltages induced into the other two stator windings are then equal because their angles of displacement are equal.

The maximum voltage induced in any one stator winding of a 115-volt synchro is 52 volts due to the turns ratio and degree of coupling. This occurs only when the stator winding is parallel to the rotor. The voltage induced in one stator winding, however, cannot be measured because the common point of the three Y-connected windings does not appear as a terminal on the outside of the synchro case. Since the end terminals of the three windings are the only stator terminals that are led outside the synchro case, only the voltage induced between any two stator terminals can be measured.

Information is transmitted in a synchro system by voltage variations in the stator circuits. A synchro receiver compares its stator voltages with those of the transmitter's stator; the amplitude and phase of both sets of voltages are related to the zero reference position. A receiver reacts to a difference in voltage values by producing a torque (in a torque system) or producing an induced voltage in the rotor of a control system. The receiver reproduces the conditions present in the transmitter to reconstruct the information. Hence, a synchro system is a suppressed-carrier transmission system. The modulation of the signal voltages represents the information being transmitted.

Obviously the receiver's supply voltage must be identical to the transmitter's. Normally both are supplied from the same source. A synchro, by the way, is not a three-phase device, though you may get that impression from the 120 degree spacing of the stator windings. Synchro supply is from a single-phase, a-c power source.

## Troubleshooting a Synchro System

In explaining synchro operation we discussed terminal voltages. Their most important practical purpose, however, is to find the electrical zero position of the rotor. Since the stator voltages are proportional to the position of the rotor, stator voltage readings are an aid in troubleshooting. There is a definite set of stator voltages for each position of the rotor. Therefore we can check a synchro's operation by comparing its voltage readings with its rotor position. For example, a voltmeter connected between S1 and S3 will read minimum voltage at the 0 degree and 180 degree positions of the rotor. Maximum voltage readings will occur at the 90 degree and 270 degree positions of the rotor.

Because synchros have a common electrical zero position, identical casualties will produce identical symptoms in all synchro systems. Therefore we can relate an electrical casualty to the mechanical movement of the rotor, and by observing the behavior of a synchro's movements we can localize a casualty to a particular circuit. For example, in a properly zeroed torque system, a short circuit from S1 to S3 will cause the receiver to position itself at 0 degrees or 180 degrees only.

We have assumed that there is no mechanical trouble when we observe the receiver's motion. This of course is not a good assumption and should be checked. Remember that a synchro generates little torque. To be sure the synchro is not jammed mechanically, deenergize the system and turn the rotor by hand. It should rotate freely throughout its operating arc. The ease with which the rotor should rotate is a matter of judgment, but experience will soon teach you how to tell whether a synchro is free or jammed. It is a poor practice to use the dial to rotate a synchro. The dial is made of light material, and is easily bent.

After the mechanical check the torque produced by a synchro can be checked. At correspondence the torque is zero. With the system energized, a slight rotation of the motor should increase the torque. Vary the input to the receiver, so as to turn it through its complete operational arc, stopping at approximately 60° intervals. Observe how the receiver follows the signal, and at each stop check the torque.

The transmitted information is reconstructed in the receiver by the stator's resultant magnetic fields acting on the rotor's magnetic fields. The stator windings are physically located 120° apart. Therefore, it is logical to assume that each stator winding has an arc in which it exercises a predominate role in reconstructing the transmitted information. Hence casualties such as opens, shorts, or reversals can be correlated with the transmitted signal position and the reaction of the receiver.

In a synchro control system the rotor of the CT is not energized by the supply voltage. The CT stator windings are connected in parallel with the CX stator windings. Thus the currents present in the CT stator are proportional to the currents in the CX stator. The magnetic fields in the CT are a reproduction of the CX stator fields. The output of a CT is the voltage induced in its rotor. A comparison of the signal input with the rotor voltage will check the operation of a CT.

## RESOLVERS

A resolver is a rotary electromechanical device whose output is a trigonometric function of its input. Physically, resolvers are similar to synchros. They are classified according to case size (diameter) in the same manner and they may be mounted with most standard synchro mounting hardware. A cutaway view of a resolver is shown in figure 4-4.

The stator of the resolver (fig. 4-4), is a cylindrical structure of slotted laminations on which two coils are wound. The rotor is composed of a shaft, laminations, 2 windings, and 4 slip rings. Compensator components, which improve the angular accuracy of resolvers, may consist of resistors or additional windings in the stator and rotor winding circuits. Compensator windings, which increase the accuracy of the resolver, are located inside the stator. Compensating (calibrating) resistors, which compensate for voltage inaccuracies and phase shifts, may be mounted either inside or outside the resolver housing.

A cylindrical frame with a standardized mounting flange houses the assembled resolver. External connections can be made to an insulated terminal board on the rear of the housing. Internal connections of the rotor and stator are terminated at the terminal board. Miniature resolvers often have unterminated lead wires brought out through the rear of the resolver, eliminating the need for a terminal block. A reference line is scribed on the face of the housing, for alignment with a similar line on the end of the rotor shaft, to determine coarse electrical zero.

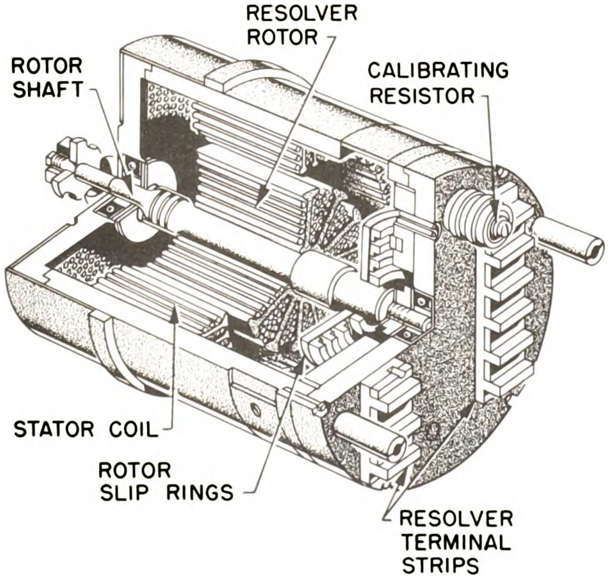

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Figure 4-4.—Cutaway of a Resolver.

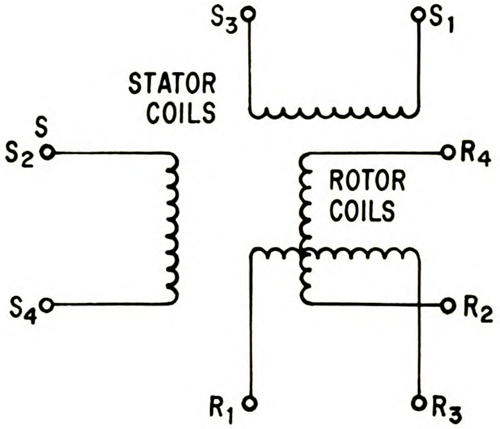

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Figure 4-5.—Resolver Schematic.

### Operation

Basically, a resolver is a transformer in which the secondary windings can be rotated with respect to the primary windings. Consequently, the amount of magnetic coupling between the primary and the secondary is variable. In its most common form it consists of a stator and a rotor, each having two separate windings placed precisely at right angles to each other (fig. 4-5).

Since the two stator windings are physically and electrically at right angles to each other, if an a-c voltage is applied to the windings there would be no magnetic coupling between them. The stator windings are mounted on the resolver housing and are stationary with respect to it.

The rotor windings of the resolver are wound at right angles to each other. Hence there is no magnetic coupling between the two windings. The rotor windings are mounted on the rotor shaft and will turn with it. The rotor is capable of unlimited rotation. Thus the rotor windings can be set at any angle with respect to the stator windings.

A resolver has both electrical and mechanical (rotational) inputs. The outputs will be proportional to the product of the electrical input and either the sine or cosine of the angle through which the rotor has been turned. Figure 4-6 shows the rotor in three different positions with respect to the stator. The stator is supplied with a fixed voltage which is assumed to be unity. Since similar action takes place in all the windings only one set is shown for clarity.

In figure 4-6A, the rotor and stator windings have an angle of 0 degrees between them. With the rotor in this position, all the flux established by the stator winding voltage cuts the rotor winding and the voltage induced in the rotor is maximum. For example, with a turns ratio between the stator and rotor of 1:1 and an input voltage of 1 volt, ignoring the small transformer losses, the output voltage will be 1 volt.

In figure 4-6B, the rotor is turned so that the two windings are displaced by 30 degrees. Now only a part of the stator flux cuts the rotor winding, and the voltage induced in the rotor is 0.866 volts (cosine of 30 degrees X 1 volt).

In figure 4-6C, the rotor is turned so that the two windings are displaced by 90 degrees. At this angle there is no magnetic coupling between the windings, and the output voltage is zero.

The output voltage corresponds numerically to the cosine function of the angular displacement between the rotor and stator. This rotor winding is therefore called the cosine winding. With the second rotor winding displaced 90 degrees from the cosine winding, the voltage induced in this winding would correspond to the sine function of the angle of displacement between the rotor and stator. This winding is called the sine winding.

Resolvers are used extensively in the FBM Weapon System for coordinate conversion and for data transmission. These devices perform electrical computations involving (1) resolution (separating a vector into its two right-angle components), (2) composition (combining the two components of a vector to produce that vector), and (3) combination (using two resolvers in a combination circuit to solve resolution and composition problems simultaneously).

### Resolver Maintenance

The maintenance of resolvers consists mainly of testing and replacement. Internal repair of a resolver normally should not be attempted aboard ship. A resolver is a precision component, whose electrical characteristics are critical, and any deviation may result in excessive errors in the system. The procedures for testing resolvers are covered in your system or instrument OP. Here we will discuss the general principles involved.

The test run on a component is determined by the functions it performs in a system or circuit. Therefore, if we know the function and operation of a component, the test that checks it can be readily understood. This is elementary and of course will hold true for resolver tests. In fact, we could go back to the zeroing procedure and just about leave it at that, for resolver

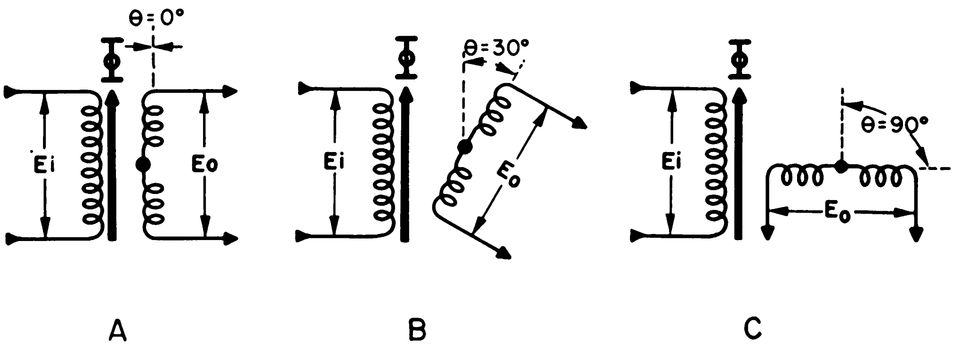

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Figure 4-6.—Resolver Principles.

maintenance starts and ends with alignment tests.

If you understand how to zero a resolver, you will have no trouble understanding the operational tests of a resolver. The zero position is our reference point for these tests. The mechanical input to the resolver is positioned at a known angle and voltage reading taken. The input voltage, which usually is a reference voltage set at a predetermined value, is checked first. Then the resolver's output voltages are read and the voltage values are listed in the OP. If you study them, you will find the output voltages are related to the input voltages by the sine and cosine functions of the angular input. For the test to be accurate, be sure the exact reference voltage is used. Moreover, if the wrong voltage is used it is quite possible you will damage some of the components in the circuit. The OP will specify the type meter to use in the test for, as you know, there is a varying degree of accuracy between meters.

Frequently the OP will list the resistance reading of the resolver windings. These are given for testing only, no repair aboard ship is intended. If it is necessary to replace a resolver, be sure the replacement is the same type. The resolver's compensating resistors are used to standardize a resolver type. Therefore, do not attempt to adjust these unless the OP gives definite instructions on it. The same thing holds true for the resolvers compensating circuits.

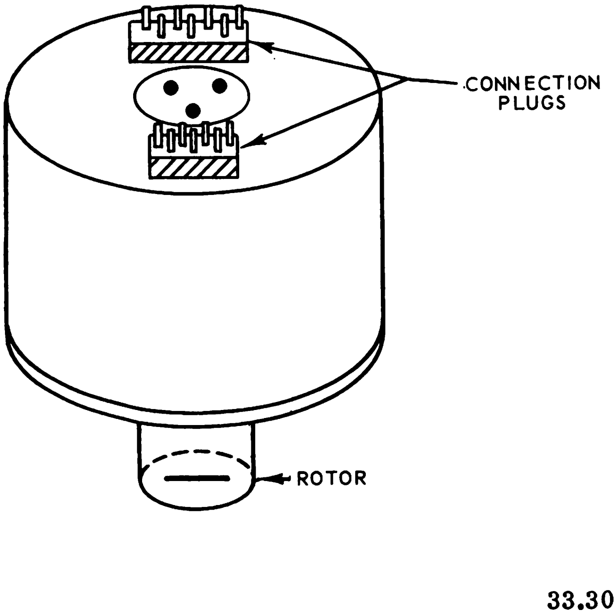

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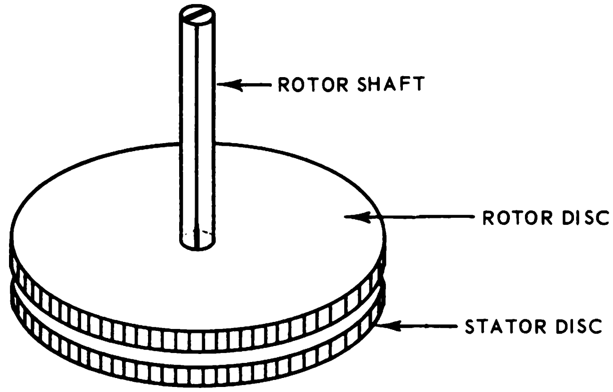
Figure 4-7.—Rotary Inductosyn.



33.301
Figure 4-8.—Relative Position of Inductosyn Plates.

INDUCTOSYNS

The Inductosyn (Farrand trademark) is similar to the resolver used in control and measurement of angles and distance. Compared to the resolver, it has greatly improved accuracy, due to its unique construction features. Two types of inductosyns have been manufactured: the rotary (fig. 4-7), to measure angles, and the linear, to measure distances. Their principles of operation however, are the same. A resolver will produce a complete cycle of the sine and cosine functions from its stators as its rotor turns through 360°. The inductosyn is so designed that a complete cycle of these two functions is produced for each 2° rotation of its rotor. Therefore, for extremely small angular displacements of 2 to 10 seconds of arc, the rotary unit will supply measurable output voltages.

Construction

An inductosyn is an air-core device, consisting of two glass plates which are precision mounted within a casing. One plate, the rotor, is movable, and the other plate, the stator, is fixed to the casing. The relative position of the two plates is shown in figure 4-8. A thin layer of silver has been deposited on the face of each disc to form a conducting surface. This silver coating is then etched out radially to form a prescribed conduction path for current flow.

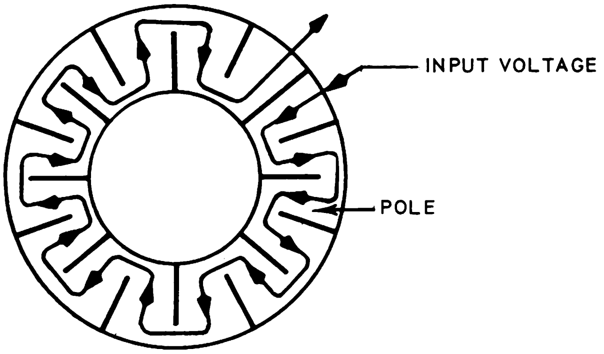


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Figure 4-9.—Simplified Diagram of Inductosyn Rotor Winding.

The etched-out portion forms an insulation medium between the paths of conduction. The two plates must be precisely constructed and aligned. The remaining silver deposits on a rotor and stator disc are placed face to face, positioned within .01 inch of one another, and the centers of the discs are aligned to within .0003 inch.

A simplified diagram of the rotor plate is shown in figure 4-9. The rotor is constructed as one continuous winding with the input and output leads connected through sliprings. Each radial turn of the winding is 1° wide and is called a POLE. There are, therefore, 360 poles to a rotor, although models could be designed with a different number of poles. Notice that a pole will go alternately toward the center of the disc, make a hairpin turn, then return to the outside edge of the disc, and again return to the center after making another hairpin turn.

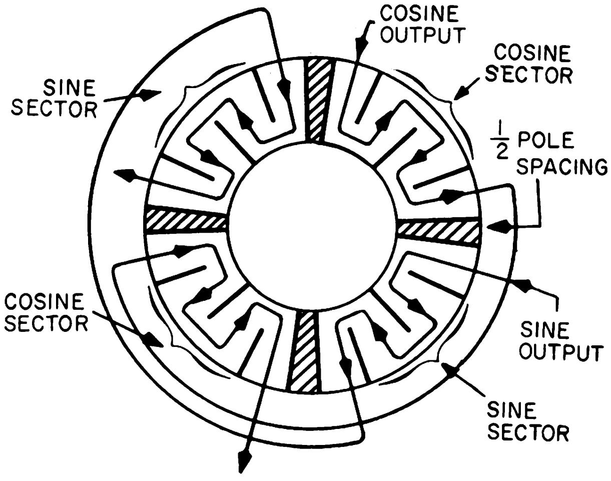

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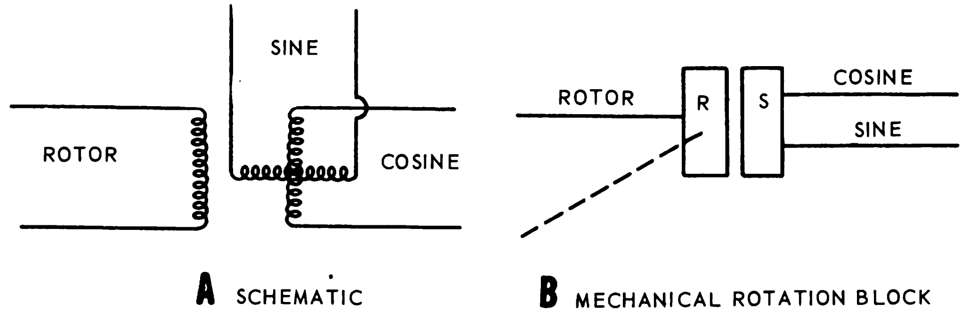
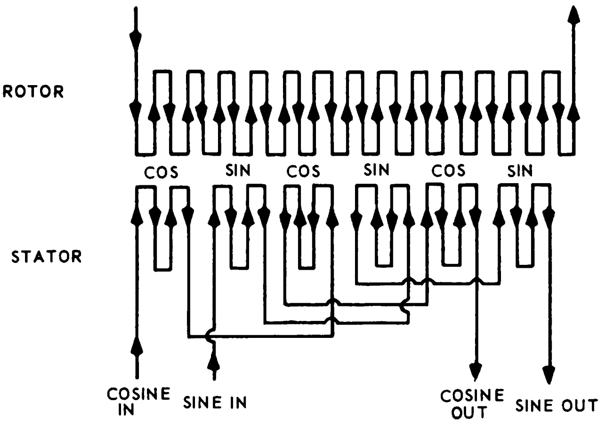
Figure 4-10.—Simplified Diagram of Inductosyn Stator Windings.

A simplified diagram of the stator plate is shown in figure 4-10. The stator forms two windings, one sine winding and one cosine winding, with their input and output leads connected to terminals. Each winding is divided into sectors that are series connected, and so placed that sine and cosine sectors will alternate. The number of sectors will vary with different inductosyn models. Some models use 2 sectors, others 16, 32, or 40 sectors for each sine and each cosine winding. The model we will describe has 80 sectors, 40 sine and 40 cosine, with each sector consisting of 4 poles 1° wide. Each



33.304

Figure 4-11.—Inductosyn Representations.



33.305
Figure 4-12.—Inductosyn Linear Representation.

sector will be placed 1/2 pole, or 1/2°, from the adjacent sectors. This pattern will produce a sine winding alternating with a cosine winding. The reason for alternating the sectors is to average out any alignment errors or manufacturing inaccuracies; thus the total error is reduced.

The schematic symbol and block diagram representations for the inductosyn are shown in figure 4-11. Figure 4-12 shows a linear representation of the rotor and stator.

General Characteristics

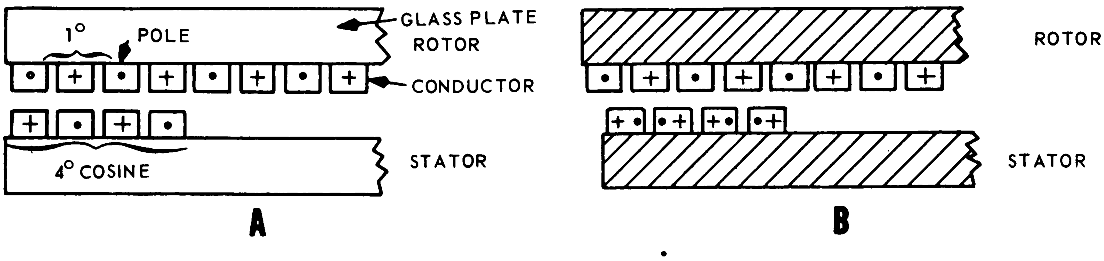
Since the inductosyn is an air-core device, the inductance component of the rotor winding will be extremely low, approximately 10 microhenries. The rotor, being constructed as one continuous winding of 360 turns of silver, will have a total d-c resistance of approximately 10 ohms. Therefore, for frequencies up to 10 KHz the inductive reactance is less than 1 ohm, and the rotor will act basically as a 10-ohm resistor. The sliprings which connect the rotor winding to the input and output leads can introduce varying amounts of resistance, up to approximately .5 ohm. To reduce the effect of these variations, an impedance matching transformer is connected in the rotor circuit to increase the input impedance to approximately 250 ohms. The stator will also have a low d-c resistance, approximately 5 ohms for each of its windings, and will utilize impedance matching devices in its circuits.

Because of this low input impedance, care must be taken to ensure that the voltage applied to any winding does not exceed one volt; otherwise the winding will be damaged. The normal voltage used is approximately .2 volt.

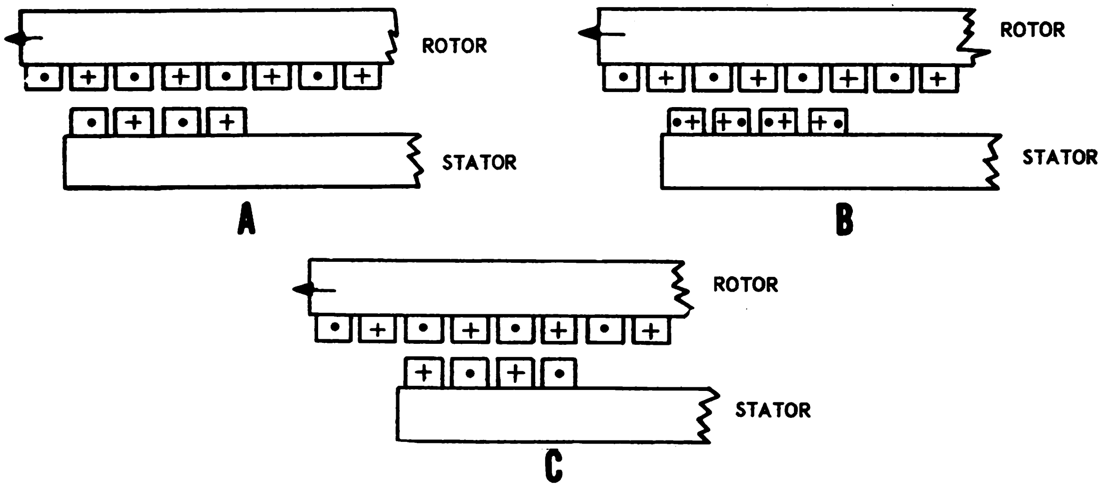
The frequency of the voltage applied to the rotor can be either 400 Hz or 10 kHz; however, in the FBM systems 10 kHz is used, since the higher frequency will provide better coupling and thus will produce a larger stator output for a given input. The coupling coefficient between the rotor and stator is very small, in the range from .0005 to .005, depending on how much distance separates the plates. This factor is small because no magnetic core is used to transfer the lines of force efficiently. Thus, .2 volt at the input will induce a maximum of .1 to 1 mv at the outputs. The induced voltages, being very small, will obviously need to be greatly amplified to be useful in a servosystem.

Theory of Operation

Figure 4-13, part A, shows the relationship between the rotor poles and the cosine winding



33.306
Figure 4-13.—Relationship between Rotor Poles and Cosine Winding at 0 Degrees and 1/2 Degree Mechanical Rotation.



33.307
Figure 4-14.—Cosine Output at 1 Degree, 1-1/2 Degree, and 2 Degree Mechanical Rotor Position.

poles at the 0 degree position. When the rotor is in this position the magnetic flux field created by the rotor voltage will cut the stator and induce maximum voltage in the cosine winding, causing its current to flow in a direction opposite to the rotor's current flow. The diagram illustrates the cross-sectional area of the turns on each plate, and the current flowing at a specific instant. You will notice that the current flow in the rotor changes direction from one pole to the next, due to the construction of the winding.

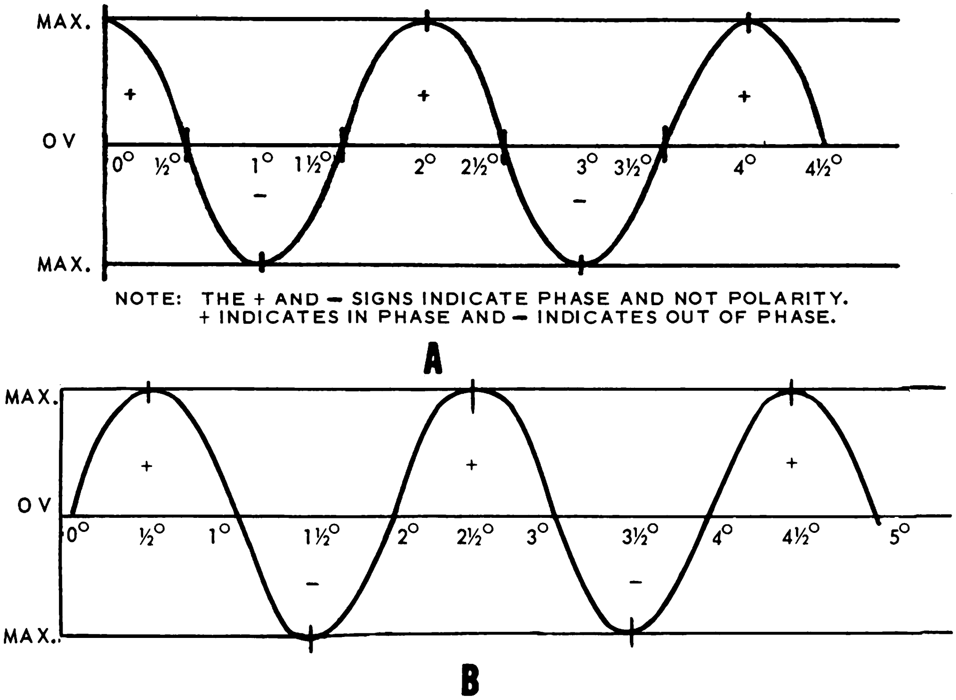
In figure 4-13, part B, the rotor has been moved from the 0 degree position by the distance of half a pole, which corresponds to one-half of a mechanical degree. Each cosine winding pole is now midway between two of the rotor winding poles. Notice that one rotor pole will tend to induce current to flow in one direction in each stator pole, while the adjacent rotor pole will tend to induce current that opposes this current. The resultant is no current flow in the cosine winding. This position corresponds to the cosine winding's 90 degree electrical position. Since the output of the cosine winding has shifted from its 0 degree electrical position to a position of 90 electrical degrees during a mechanical rotor movement of 1/2 degree, the effective electronic gear ratio is 180:1.

In figure 4-14, part A, the rotor has been moved another 1/2 degree to the 1 degree mechanical position. Each cosine turn will again have maximum voltage induced in it, but notice that the current now flows in a direction opposite to the current that was induced in this winding at the 0 degree mechanical position, as shown in figure 4-13, part A.

In figure 4-14, part B, the rotor has been turned to its 1-1/2 degree mechanical position. This position corresponds to a cosine output of 270 electrical degrees, and the illustration shows that the resultant current flow in the cosine winding will again be zero.

The 2 degree mechanical rotor position, shown in figure 4-14, part C, indicates that the cosine winding output has shifted a full 360 degrees electrically, since the induced current is again maximum and in phase with the current that was induced at the 0 degree mechanical position. The cosine winding output will repeat this pattern for each rotor movement of 2 mechanical degrees. There are 180 possible electrical cycles for one complete 360 degree mechanical rotation of the rotor. A plot of the rms voltage induced in the cosine and sine windings during rotor movement is shown in figure 4-15. To produce the sine function output, there is a 1/2 degree space after the cosine sector, which will produce a 90 electrical degree shift.

In the 0 degree mechanical position, shown in figure 4-16, the cosine winding output is maximum but the sine winding output is zero. The cycle for



NOTE: THE + AND − SIGNS INDICATE PHASE AND NOT POLARITY.
+ INDICATES IN PHASE AND − INDICATES OUT OF PHASE.

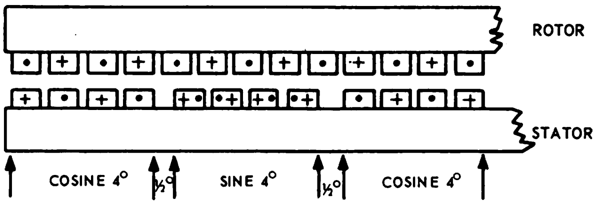
77.21

Figure 4-15.—Plot of the rms Voltage Induced in the Cosine (A) and Sine (B) Windings During Rotor Rotation.

the sine function is repeated in the same manner as the cosine function, except that the sine output is shifted 90 electrical degrees.

MICROSYN

The 8-pole microsyn is used throughout the FBM guidance systems. The main reason for using an 8-pole rather than a 4-pole microsyn is that a larger error signal will be produced for the same amount of mechanical rotor movement.



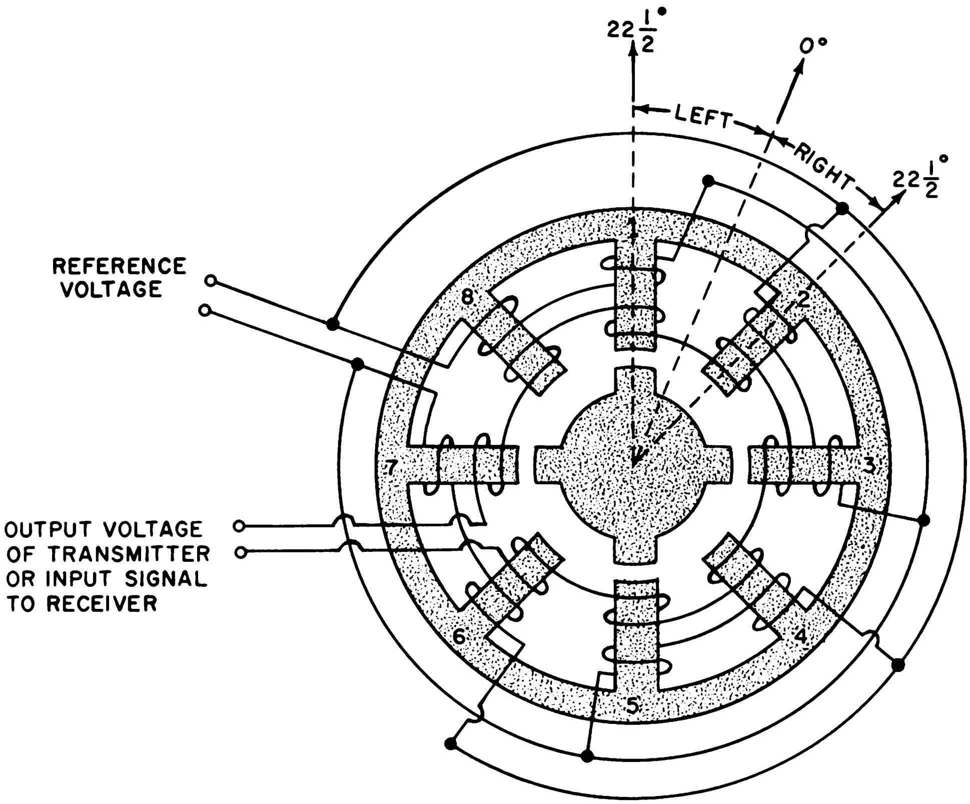
33.308

Figure 4-16.—Relationship Between Cosine and Sine Winding Outputs of 0 Degree Mechanical Rotor Position.

The 8-pole microsyn (fig. 4-17) can be used either as a transmitter or a receiver. In either event, the unit consists of a 4-pole ferrite rotor and a stator consisting of 8 poles; the rotor poles are displaced from one another by 90 degrees, while the stator poles are situated 45 degrees apart. A primary and a secondary coil are wound on each stator pole. The rotor itself has no windings, and serves only to change the reluctance of the magnetic paths between the stator poles. The rotor will usually be mounted on jeweled bearings with self-magnetic suspension to obtain a near-frictionless surface.

Basically, the 8-pole microsyn operates the same as the 4-pole unit. We will discuss only the operation of the 8-pole unit here.

When the unit is used as a transmitter, its output is a voltage whose phase is determined by the direction of the rotor movement. The adjacent coils in the primary circuit are connected in series, and are excited by an 800 cycle reference voltage. These coils are wound so that the flux patterns created are set up as follows: pole 1 aids pole 8, pole 2 aids pole 3,



33.309

Figure 4-17.—8-Pole Microsyn Torque or Signal Generator.

pole 4 aids pole 5 and pole 6 aids pole 7. If the rotor is aligned to the zero position, equal amounts of the ferrite rotor will lie under each of the eight stator pole faces. When the rotor is in this position, equal voltages will be induced in the secondary coils. Due to the method of winding, the combined voltages induced in the odd pole secondaries will oppose the combined voltages induced in the even pole secondaries. The resultant combined voltages, being equal and opposite in phase, null each other and result in a zero transmitter output.

If the rotor is turned 22-1/2 degrees to the right (from its zero position) the amounts of ferrite rotor lying under the even poles will exceed those under the odd poles. The total voltage induced in the even pole secondary coils will now be greater than the total voltage induced in the odd pole secondary coils. Under this condition the phase of the output voltage is that of the voltage induced in the secondary coils of the even poles, and the amplitude of the output voltage will be equal to the voltage induced in the even secondary coils minus that induced in the odd secondary coils.

Figure 4-17 also shows the rotor turned 22-1/2 degrees to the left (from its zero position). With the rotor in this position, the amounts of ferrite rotor lying under the odd poles will exceed those amounts under the even poles. Under this condition the magnitude of the output voltage will equal the voltage induced in the odd secondary coils minus that induced in the even secondary coils. Also, the phase of the output voltage will be that of the voltage induced in the odd secondary coils.

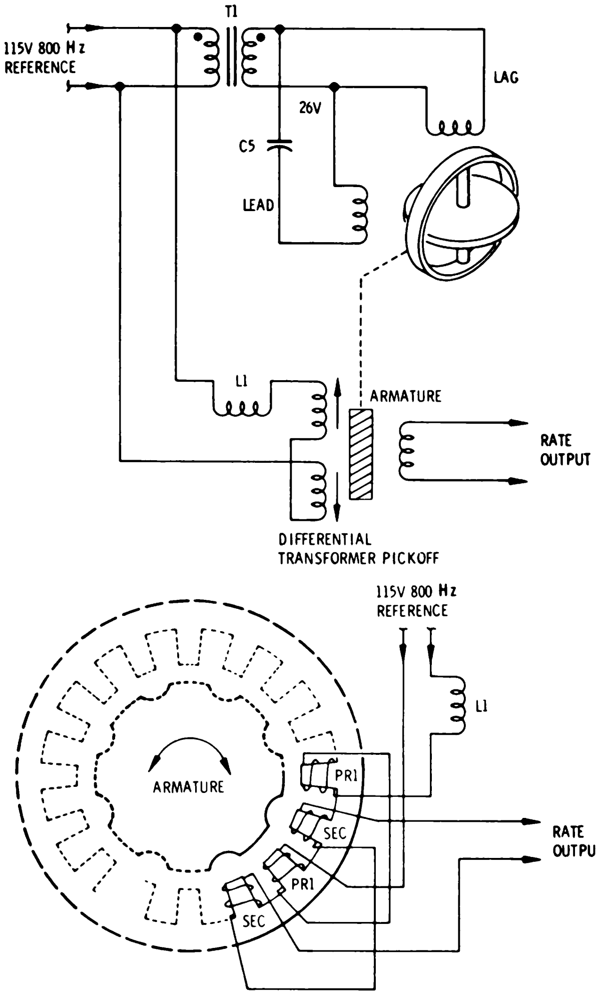
When the unit is to be used as a receiver, the rotor is free to turn. For this example, assume that the reference voltage alone is applied to the primary coils. The resulting magnetic fields produced by the eight primary coils will cause the rotor to align at its zero position. If a voltage that is in phase with the reference voltage is applied to the secondary coils, the flux produced by the even pole secondaries will aid the primary flux, and the flux created by the odd pole secondaries will oppose the primary flux. Thus the magnetic field set up by the even poles will be stronger than that of the odd poles. Therefore, a torque will be exerted on the rotor, causing it to rotate until it is aligned with the resultant flux field.

If the phase of the voltage applied to the secondary coils is reversed, the direction of the torque exerted on the rotor will be reversed.

On occasion, you may encounter a microsyn consisting of two concentric 8-pole stators, and a rotor that fits between them. Here the basic operating principle is the same as we have previously discussed, except that during operation the inner stator provides magnetic suspension for the rotor, while the outer stator is used to generate the signal or torque. This type of microsyn is sometimes referred to as a ducosyn.

## DIFFERENTIAL TRANSFORMER

The differential transformer, (fig. 4-18) is a variation of the "E" pickoff transformer that is covered in Synchro, Servo, and Gyro Fundamentals, NAVEDTRA 10105. The primary of the differential transformer is wired series-opposed and supplied with 115 volts 800 Hz reference voltage. The output signal representing the rate gyro precession is taken from the secondary winding. In a null position induced voltages from the two primary windings cancel each other and the signal output is zero. Armature movement in one direction induces a voltage in the secondary that is in phase with the reference voltage while movement in the opposite direction will induce a voltage that is 180 degrees out of phase with the reference voltage. Thus as the rate gyro precesses it rotates the armature and the differential transformer provides an electrical output signal. The signal's amplitude is proportional to the amount of precession, while its phase depends on the direction of precession.



TYPICAL DIFFERENTIAL TRANSFORMER CONFIGURATION

161.41

Figure 4-18.—Rate Gyro Differential Transformer, Schematic Diagram.

## BRIDGE CIRCUITS

Bridge circuits can be used to transmit data between remote instruments. Their principles of operation are identical to the bridge circuits used in electrical meters, (Wheatstone bridge) covered in Basic Electricity, NAVEDTRA 10086-B.

### Balanced Bridge Circuits

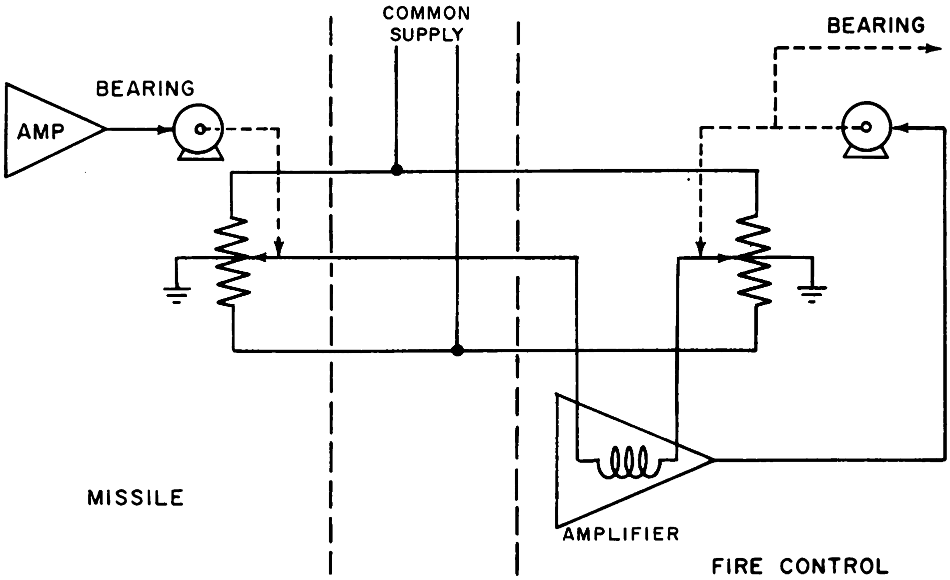
Essentially, a balanced bridge circuit has two legs or branches whose electrical characteristics are identical. A balanced bridge circuit consisting of two identical potentiometers connected in parallel with a common source of supply is shown in figure 4-19. The wipers of the potentiometers are connected through a signal circuit that includes an input transformer in a servoloop. If the wipers are not at the same potential, current will flow through the signal circuit. The amount and direction of the current flow is determined by the potential difference between the wipers.

Assume we wish to transmit a bearing angle that is measured in the missile to an indicator in fire control. The device that drives bearing in the missile also drives the wiper of the potentiometer. The bearing servo in fire control will drive the followup potentiometer wiper until there is no current flow in the signal circuit. This condition will occur when both wipers are at the same potential and hence at the same position. Thus the followup wiper will follow any movement of the signal wiper.

The ground connections are at the center of the potentiometer windings and represent a zero reference position from which bearing is measured. When the wipers are above these points, bearing is to the right of the reference, while below the points bearing is to the left of the reference. When the wipers are on the ground point, bearing is at the reference position and the ground connections shunt out the signal circuit. The ground connections do not have to exist physically for the circuit to operate. Since the center of the potentiometers are at the same potential a phantom shunt connection will exist between the two points.

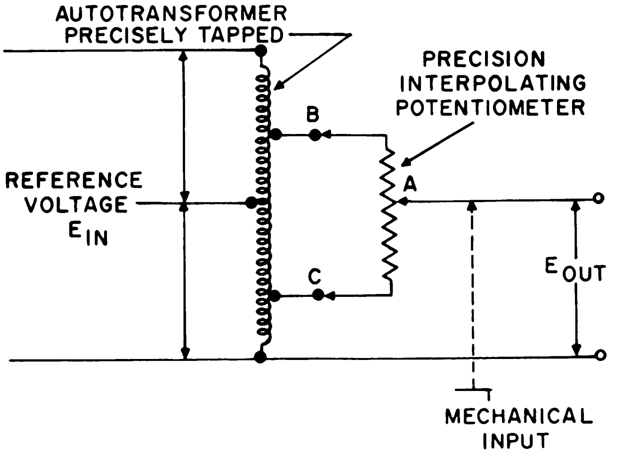
## PRECISION LINEAR VARIABLE RESISTOR

A precision linear variable resistor, also called Vernistat, develops an analog voltage that represents a quantity in the fire control problem. The linear variable resistor is made up of an autotransformer and a linear potentiometer (fig. 4-20). A reference voltage is applied across the transformer which has many output taps. The voltage across the potentiometer winding depends on the positions of contacts B and C. The percentage of the reference voltage present at some of the transformer taps is shown in figure 4-21. If the contacts are moved along the transformer taps, the voltage across the potentiometer would vary in increments or steps. The contacts are positioned to provide the desired voltage across the potentiometer. The proper position of the contacts is dependent upon the output requirements. That is, the scale factor used in the output analog circuit. Normally, the potential at the limits of the potentiometer represent the maximum and the minimum values of the analog quantity.



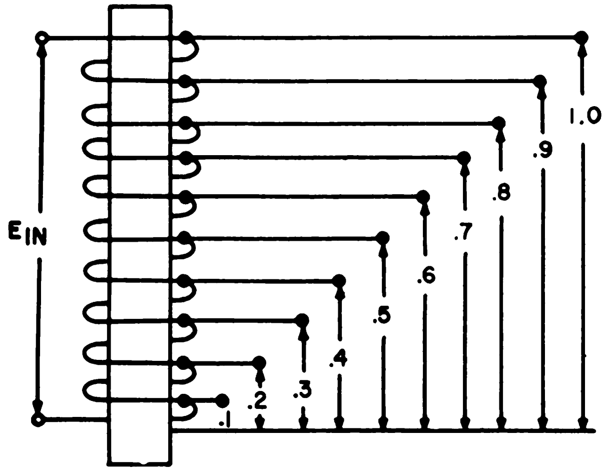
12.282

Figure 4-19.—Balanced Bridge Circuit.


AUTOTRANSFORMER PRECISELY TAPPED
PRECISION INTERPOLATING POTENTIOMETER
B
A
C
REFERENCE VOLTAGE $E_{IN}$
$E_{OUT}$
MECHANICAL INPUT

177.22
Figure 4-20.—Precision Linear Variable Resistor, (Vernistat).

The resistance of the potentiometer winding is linear. Thus, as the wiper arm, contact A, is moved from limit-to-limit, there is a straight-line relationship between the output voltage and the resistance between the wiper arm and either of the limits. Since the resistance of the potentiometer winding is in parallel with the transformer section supplying its voltage, the potentiometer interpolates between the transformer voltage levels to produce a linear voltage output. The wiper arm is positioned by a mechanical input representing the quantity for which we wish to develop an analog voltage. Since the potentiometer resistance is linear, the output signal voltage bears a one-to-one relationship with the position of the wiper arm. Therefore, the position of the wiper arm determines the magnitude of the output voltage and hence of the quantity it represents.

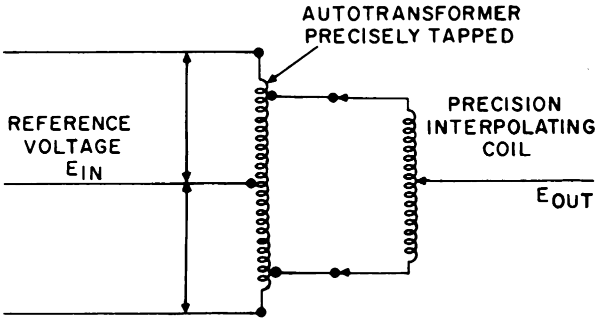


166.11
Figure 4-21.—Voltage Percentage at Transformer Taps.

The inductive voltage divider operates in the same manner as a linear variable resistor. Inductive voltage dividers have an inductive coil in parallel with the transformer (fig. 4-22). The output voltage is taken from the wiper arm of the coil. The magnitude of the output voltage is determined by the inductive reactance of the coil in the same way the resistance of the potentiometer determined the output of its circuit. Depending upon use, these devices can be made to multiply, divide, add, or subtract. The function is determined by the circuit arrangement.

TACHOMETER GENERATORS

A tachometer generator, commonly called "tach", produces a voltage whose magnitude is proportional to the number of revolutions its rotor makes per unit of time. The phase or polarity of the output voltage is determined by the direction the rotor is turned. Therefore, a tach's output voltage is representative of the speed and the direction of the rotor's motion,


AUTOTRANSFORMER PRECISELY TAPPED
REFERENCE VOLTAGE $E_{IN}$
PRECISION INTERPOLATING COIL
$E_{OUT}$

177.23
Figure 4-22.—Inductive Voltage Divider.

in other words its velocity. The tach's rotor is mechanically coupled to the drive shaft of the unit whose velocity we wish to measure. Thus its output voltage is an analog representation of the unit's velocity or rate of motion. Tachs are sometimes referred to as rate generators.

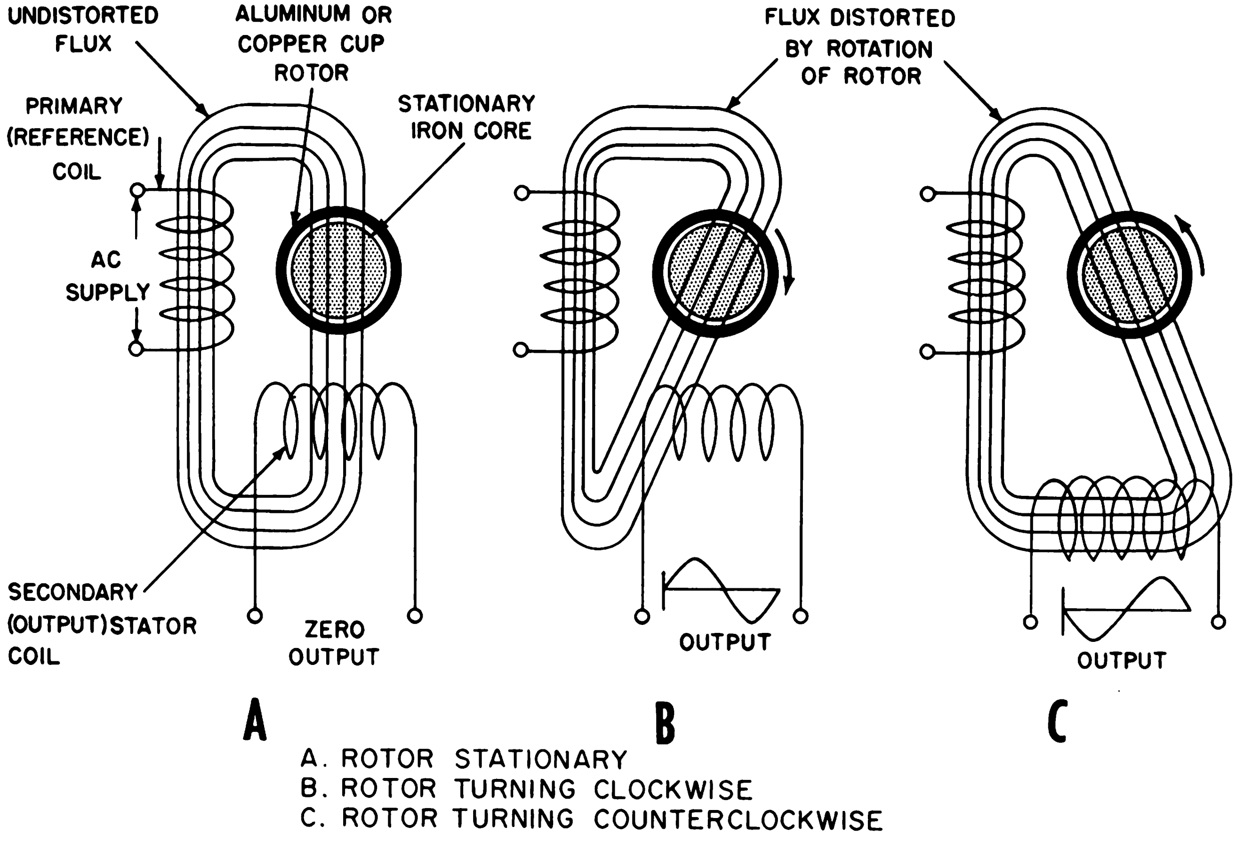
### AC Tachometer Generators

The construction and operating principles of the a-c drag-cup generator is shown in figure 4-23. The tach has two stator windings located 90 degrees apart from each other and an aluminum or copper cup rotor. The rotor rotates around a stationary soft-iron magnetic core. One stator winding, called the reference or primary winding is energized by a reference a-c source. The other stator winding is the tach's output or secondary winding.

The tach's operation is based on transformer principles. The voltage applied to the primary winding creates a magnetic field. If the drag-cup rotor is stationary, the magnetic field is at right angles to the secondary winding, (fig. 4-23A).

When the rotor of the tach is turned, it distorts the magnetic field so that it is no longer 90 electrical degrees from the secondary winding. Flux linkage is created with the secondary winding and a voltage is induced, (fig. 4-23B, C). The amount the magnetic field will be disturbed is determined by the angular velocity of the rotor. Therefore, the magnitude of the voltage induced in the secondary winding is proportional to the rotor's velocity.

The direction of the magnetic field's distortion is determined by the direction of the rotor's motion. If the rotor is turned in one direction


UNDISTORTED FLUX
ALUMINUM OR COPPER CUP ROTOR
PRIMARY (REFERENCE) COIL
STATIONARY IRON CORE
AC SUPPLY
SECONDARY (OUTPUT) STATOR COIL
ZERO OUTPUT
FLUX DISTORTED BY ROTATION OF ROTOR
OUTPUT
OUTPUT
A
B
C
A. ROTOR STATIONARY
B. ROTOR TURNING CLOCKWISE
C. ROTOR TURNING COUNTERCLOCKWISE

55.40

Figure 4-23.—AC Drag-Cup Tachometer Generator.

the lines of flux will cut the secondary winding in one direction. If the motion of the rotor is reversed the lines of flux will cut the secondary winding in the opposite direction. The phase of the voltage induced in the secondary winding measured with respect to the phase of the supply voltage is determined by the direction of the rotor's motion.

The frequency of the tach's output voltage is the same as the frequency of the reference voltage. This is reasonable since the magnetic field produced by the primary winding fluctuates at the supply's frequency. The output voltage is generated by the alternating flux field cutting the secondary winding; therefore, the output voltage must have the same frequency as the supply voltage.

Another type of a-c tach has a squirrel-cage rotor. Otherwise its construction and principles of operation are identical to the drag-cup tach.

### DC Tachometer Generators

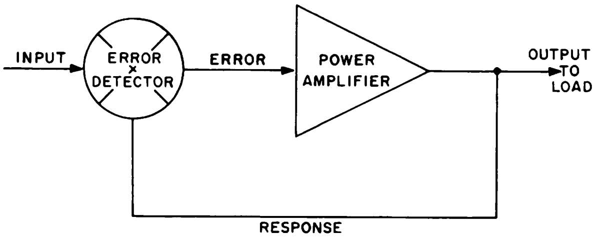
The d-c tachometer generator employs the same principles of magnetic coupling between the reference winding and the output winding as the a-c tach. However, the d-c tach has a stationary primary magnetic field. This magnetic field is frequently supplied by permanent magnets built into the tach. The amount of voltage induced in the rotor winding is proportional to the magnetic flux lines the winding cuts. The polarity of the output voltage is determined by the direction in which the rotor cuts the lines of magnetic flux.

# CHAPTER 5

# SERVOMECHANISMS

Operation of the fire control equipment is almost fully automatic and largely dependent on data from remote sources. To obtain smooth, continuous and accurate operation, the information flow is normally best controlled by itself. But the power produced by the data sensors in the transmission systems is not large enough to do appreciable amounts of work. Much of the automatic operation of the Weapon System has its origin in control devices known as servomechanisms, called "servos" for short.

Servos are part of a broad class of control systems that operate on the principle of feedback, (fig. 5-1). The input is an order signal that is applied to the error detector and indicates the desired action of the servo. The other signal to the error detector is a feedback or response signal that is proportional to the reaction of the servo. The error detector subtracts the response from the order signal to get the amount of difference, or error, which is the input signal to the amplifier. If there is a difference, corrective action automatically takes place. The error reducer, which could be an electric motor, drives the servo load and the response line to eliminate the error. Notice that response forms a closed loop within the servo, there is a complete path through the servo to the load and back to the error detector. It is this closed loop that provides the automatic followup feature in servos.



12.284
Figure 5-1.—Block Diagram of an Elementary Servo.

A servo is an entire system and must have the minimum number of components shown in the block diagram. It may have more components but regardless of the number, the components all work together as a system or team. Together these interconnected components measure, transmit, compare, amplify, and control quantities.

Servo concepts are covered in the basic Rate Training Manual—Synchros, Servos, and Gyro Fundamentals, NavPers 10105. The purpose of this chapter is to discuss a basic servomechanism and to cover the application of the basic servo concepts in fire control equipment. It is not practical to cover all the circuits in the fire control system, for servos have numerous applications and there are just about as many different types of servos as there are jobs for servos to do.

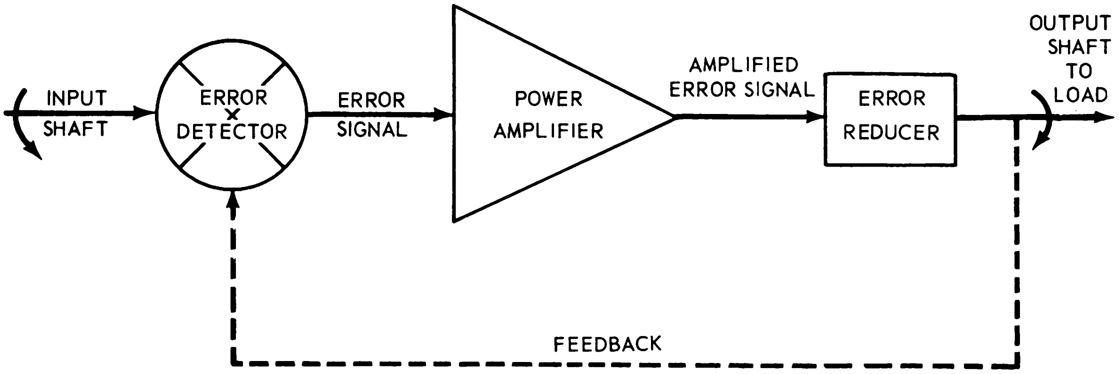
## SERVO REQUIREMENTS

So far, we have talked about the essential elements in servos—the "bare bones," so to speak. We reduced a servo to its minimum number of functional blocks. Now we will expand the number of working blocks from two to three, and then discuss each in turn.

### SERVO FUNCTIONAL SECTIONS

Figure 5-2 is a three-element block diagram of the elementary servo shown in figure 5-1. Each block has a label that describes its function.

The new block diagram differs from the first one in that the power amplifier has been divided into two parts: an AMPLIFIER and an ERROR REDUCER. The amplifier increases the weak error signal, and it controls the error reducer. We have coined the term error reducer because



12.285

Figure 5-2.—Block Diagram of an Elementary Servo.

the name closely describes the function of this servo section, which is to drive the output of the servo until it is equal to the input, thus reducing the error nearly to zero. Keep in mind that there can never be zero error. The error reducer must receive an error signal before it can control the output. However, the error signal should be kept as small as possible.

In the servo in figure 5-2, the input, output, and feedback devices are mechanical shafting; the error detector is an electromechanical device; the amplifier is electronic; and the error reducer is an electromechanical unit.

Earlier, we described a servo as any device that uses the principle of feedback. It can also be defined as a mechanism whose output tries to reproduce its input. Let's look at how the servo blocked out in figure 5-2 works, based on this point of view. Assume that the input and the output shafts are at the same position. There is no error between them, and so there will be no error signal to the amplifier. Therefore, the error reducer will not receive a correcting signal and the servo will not move. But if the input shaft is turned to a new position, there will be an instantaneous angular difference between the positions of the input and output shafts. The difference is detected and measured by the error detector. The input and feedback shafts are both inputs to the error detecting device, which, as we said before, is electromechanical. Since the feedback shaft is geared to the output shaft, the feedback duplicates any position and motion of the output. Therefore, knowledge of what the output shaft is doing is fed back over the feedback line to the error detector. Here, the positions of the input shaft and output shaft are compared. The error detector measures any difference between them, and then it changes mechanical position error into an electrical error signal. The electrical error output of the error detector is directly proportional to the angular difference between the input and output shafts.

The electrical error signal is relatively weak. So, it must be amplified. After it is amplified, it is sent to the error reducer. Here, the error signal is changed from its electrical form to a proportional mechanical signal. The error reducer drives the output shaft in a direction which reduces the error between the output and input shafts. As the output shaft turns, so does the feedback line. But it turns in a direction that reduces the difference between the input and feedback signals. When the output and input shafts are in agreement, the output of the error detector is zero. The amplifier "sees" no signal at its input and the servo stops.

If the input shaft is turned at a constant velocity, the output shaft should turn to the same position as the input shaft, and follow it at the same speed and in the same direction. If the input shaft were to speed up, then reverse its direction, the output shaft should faithfully reproduce these mechanical gymnastics; and all the while the two shafts should remain closely aligned. If at any time they do not, then the error detector will produce an error signal. This signal is amplified and sent to the error reducer. It then drives the output shaft until the error between the input and output is as nearly zero as possible. When this condition exists, the servo is said to be "nulled". Other terms that describe zero or nearly zero error are: synchronized, in synchronism, and in correspondence.

In the preceding paragraphs of this chapter we have described the sections of a servo and their functions. You learned that the input is the controlling quantity. It has been described as the displacement of a shaft. In practical servos the input is generally an electrical quantity which represents a shaft position. The servo error is the difference between the input and output of the servo. The error detector is the device which compares the input with the servo output. The error reducer is essentially the prime mover of the servo. It is controlled by the amplifier section, which simply increases the strength of the error signal so that it can move the error reducer.

Now let us discuss the demands placed upon servo components to meet the requirements in fire control equipment.

## INPUT SIGNAL

Sensors measure the input and output of a servo and express them in suitable form. The operating principles of most of the sensors used in FC servos were covered in the preceding chapter. Sensors used with gyros are covered in chapter 7 of this training manual.

### Signal Speed

Use of a multispeed transmission system increases the accuracy of a servo. But a multispeed system introduces a problem—how can the amplifier tell when it is, or should be, receiving a fine or a coarse signal? A synchronizing circuit is included in the servo to sense how far the load is from the ordered position and to switch the appropriate signal into control. The selection is based on the size of the error signal the circuit receives. The coarse signal is the predominate factor in the selection, since it is a measure of the servo position throughout its limits of operation. The coarse signal drives the system into approximate synchronization, where the fine signal is shifted into control. In multispeed transmission systems a stickoff voltage is introduced into the signal circuit to eliminate any possibility of the system synchronizing at a false null point.

### Filters

Input signals to a servo always contain some roughness, such as noise in an electrical signal. This roughness must be eliminated to obtain smooth operation. The frequency spectrum of the signal is examined by filter and quadrature rejector circuits which shunt the noise frequency away from the amplifier.

### Modulators/Demodulators

The type of power used in a servo is determined by its job. Some servos have a d-c error voltage and an a-c amplifier or motor. Before the d-c voltage can be used it must be converted to an a-c voltage whose amplitude and phase are dependent on the input amplitude and polarity respectively. In other servos the input signal may have a different frequency than the amplifier or motor. In these servos the frequency must be shifted from 400 Hz to 800 Hz or 10 kHz. Circuits that convert d-c to a-c or shift the frequency of the a-c voltage are called modulators. Modulation is the process by which the amplitude, frequency, or phase of a carrier voltage (called carrier wave) is varied with a signal voltage containing data. In other words the data voltage is superimposed on the carrier voltage.

On the other hand, in some servos the error voltage is a-c and the amplifier or motor uses d-c voltage. In this case a demodulator circuit is needed. Demodulation is the process of extracting the signal voltage from a modulated carrier wave.

### Type Signals

The input signal to the servo can represent a position or a velocity order. The type signal used depends on the requirements of the output. If we need to drive a quantity to a fixed position and then keep it synchronized, such as the latitude input to FC, obviously a position signal is used. If we need to know the rate of change of a quantity, such as own ship motion in the missile motion computations, a velocity signal is required.

Some signals are in digital form and must be converted to an analog form for use in the servo. Basically, digital quantities are produced by a counting process while analog quantities are produced by a measuring process. Therefore, a circuit that measures the number contained in the digital signal is used to convert the signal form.

## AMPLIFIERS

Obviously, the primary function of the amplifier is to increase the strength of the error signal but servoamplifiers have several other inherent advantages:

1. Flat amplitude response or gain over the frequency band of interest.
2. Small and fixed phase shift of the output with respect to a reference voltage.
3. Output circuit impedance is designed to match load impedance for efficient power transfer.
4. Low noise level.

The frequency bandwidth, the phase shift, and the amplification factors of an amplifier help to explain the use of various types of servoamplifiers in FC equipment. Where standard amplifiers are used the input signal must be within the limits of the amplifier's operation. But the servo error signal generators vary. Where the error signal amplitude is too small for the standard amplifier, a preamplifier is used. A preamplifier is a separate stage used to bring the error signal characteristics within the limits of the amplifier.

## RESPONSE

Fire control requires a servosystem to operate smoothly, rapidly, and with as few errors as possible. To obtain these operational characteristics, one quality is counterbalanced against the other. To increase the rapidity of response of the system to a signal, the gain is increased. This also tends to reduce error in the system. But a high gain or "tight" servo has a tendency to overshoot and oscillate, or, in other words to be unstable. Response or synchronization time is the time the servo requires to settle down in synchronization to an order signal.

## FEEDBACK—DAMPING

A servo will drive its load to the correspondence position. The servo's error signal and output torque are zero at correspondence, but due to the load's inertia it will continue to move. As the correspondence point is passed, the error signal tends to reverse the direction of movement. But a short time is needed to stop the load; and, during this time, the load will continue to move away from correspondence. When it does stop, the error signal will drive the load back towards correspondence. At correspondence the load has again acquired sufficient inertia to drive on past. The result is a series of overtravels of the correspondence point.

This condition is called "hunting", and is a characteristic which must be corrected in all servos. Obviously, hunting reduces the smoothness of the servo's followup action and increases its synchronization time. To overcome hunting, the servo must anticipate the load's inertia and its position with respect to the correspondence point.

When a servo is hunting, its oscillations about the correspondence point are of a low frequency. A servo with a high gain amplifier has a tendency to oscillate at a high frequency with a low amplitude. The high frequency oscillations are started by some type of disturbance or variation such as random noise in the electrical section of the servo or lost motion in the mechanical section. Once the oscillations are started, the high gain of the amplifier tends to assist them, while the inertia of the load continues to reintroduce the error caused by the oscillation.

To obtain smoothness of operation, the system's gain is damped. Damping can be obtained by either introducing a feedback voltage in opposition to the signal voltage or placing a physical restraint on the servo output. The function of damping is to reduce the amplitude and duration of the oscillations that may exist in the system. Thus to obtain the desired operational characteristics one quality is counterbalanced against the other.

## FIRE CONTROL SERVOS

The FC equipment contains many different types of modules used in servos. It is the purpose of this chapter to explain the function of these modules without going too deep into an analysis of their internal circuits. Therefore, simplified versions of representative circuits will be used. In addition, understanding of the module functions should not depend upon knowledge of the fire control problem and its symbol system. We will start with a straightforward analog servo that transmits a relatively simple quantity.

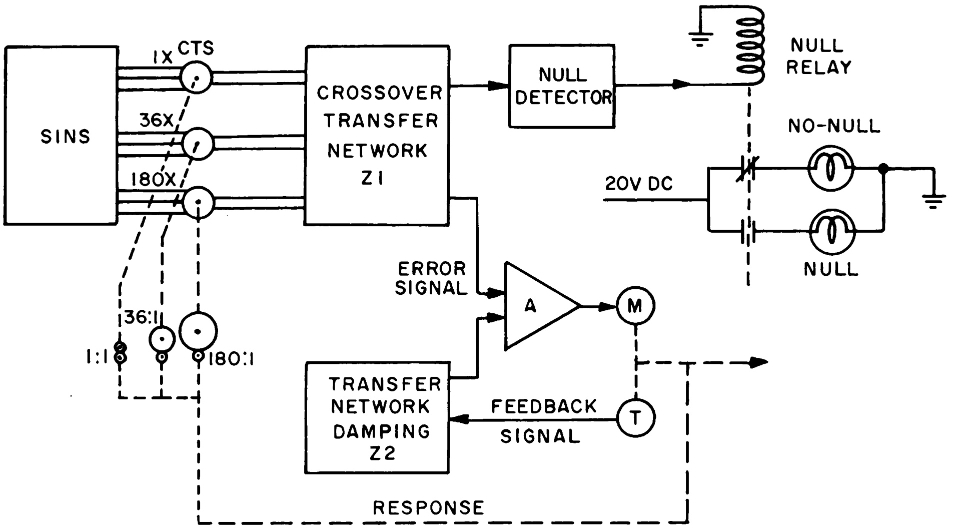


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Figure 5-3.—Block Diagram of the Latitude Servo.

## LATITUDE SERVO

The latitude, Lyo servo (fig. 5-3), receives Lyo from SINS as a three-speed input on control transformers (CT). The term "speed" refers to the gearing of the CTs which operate at 1 speed (coarse or low), 36 speed (intermediate), and 180 speed (fine or high). There are two outputs from the servo. The first, the null error signal, drives a null detector, which, in turn, operates a relay alarm indicating circuit. The second output, Lyo, at the servomotor shaft, drives the analog-digital (A/D) encoder and the resolvers. The motor also drives the response line and an a-c tachometer generator which furnishes a velocity feedback signal. Notice that the response line is geared to the CTs forming a closed loop.

### Crossover Transfer Network

The crossover transfer network determines the specific point at which control is switched from the coarse input to the intermediate or the fine input. In addition, the crossover network selects and reduces the three-speed signals to a suitable level for the system null detector circuit.

Figure 5-4 is a simplified diagram of the crossover network signal switching circuit. The fine signal circuit is from pin P15 through R1 and the diode network to pin P3, the common return lead for the signal circuit. The fine signal is clipped to a 1.5 volt level by the diode network. The intermediate signal circuit is from pin P12 through R3 and R14 back to pin P3. In parallel with this section of the circuit is the back-to-back zener diodes and the conventional diode switching network. The zener diodes clip the intermediate signal at a 3.3 volt level in the parallel circuit. The return side of the parallel circuit is through R8 and the fine signal diode network back to P3. Therefore, with both signals in the circuit the output voltage at P8 will be proportional to the sum of the two signals. The coarse signal circuit is from pin P11 through R5, the switching diode network, R9, and the fine and intermediate circuits back to P3. Thus the coarse signal is tied in parallel with the output of the other two signals.

When the servo is far out of synchronism, the coarse CT assumes control of the network and supplies the error signal to the amplifier. As the servo drives toward synchronism the level of the coarse signal drops. When the coarse signal drops below the level of the combined fine and intermediate signals, it is switched out of the circuit by its diode network. The combined fine and intermediate signal takes command of the servo and supplies the error gnal to the amplifier. When the intermediate gnal drops below 3.3 volts, it is switched out the circuit by its diode network and only the ne signal has control. The fine signal drives e servo to a very fine null. In normal operation e fine CT will now maintain control of the ervo.

The three-speed inputs are also applied to a milar diode switching and resistor attenuating twork to reduce the signals to a suitable vel for the system null detector, (fig. 5-3). a servo with two-speed inputs, fine and arse, the crossover network operates in the me manner. Obviously, instead of the combined ne and intermediate signals only the fine signal used.)

The feedback signal from the tachometer is plied to the amplifier through the transfer twork Z2. The feedback signal is proportional the velocity of the servo output and provides ror-rate damping for servo stability. The ansfer network controls the output level of e damping signal and provides an impedance atch between the tach and the amplifier.

### rvoamplifier

The error and damping signals are combined the input signal circuit of the amplifier, g. 5-5). The first three stages of amplification erate as class A amplifiers to increase the rength of the signal. A class A amplifier operates in the linear portion of its characteristic curve and produces an amplified duplication of the input signal. The fourth or output stage of the amplifier is a power stage connected in push-pull. The amplified signal is coupled to the power stage by a transformer that acts as the inverter stage for the push-pull operation. The amplifier provides a 0 to 20 volt, 400 Hz output to the control winding of the servomotor. The amplitude of this voltage is proportional to the amplifier's input error signal and its phase is the same as the error signal. The amplifier also provides 23 volts d-c to the null detector circuit and 25 volts 400 Hz stickoff voltage to the transfer network.

### Servomotor

The servomotor is an a-c induction motor that operates as a conventional split-phase bidirectional servomotor. Its reference winding is supplied with 115 v. 400 Hz reference voltage that has been shifted 90 degrees. Its control winding is supplied from the amplifier with a voltage that is either in phase or 180 degrees out of phase with the reference voltage. Motor speed is determined by the amplitude of the voltage on the control winding, while the direction of motor rotation is determined by the phase relationship between the voltages on the reference winding and on the control winding. The motor drives the response line, the tachometer, the resolvers, and the encoders.

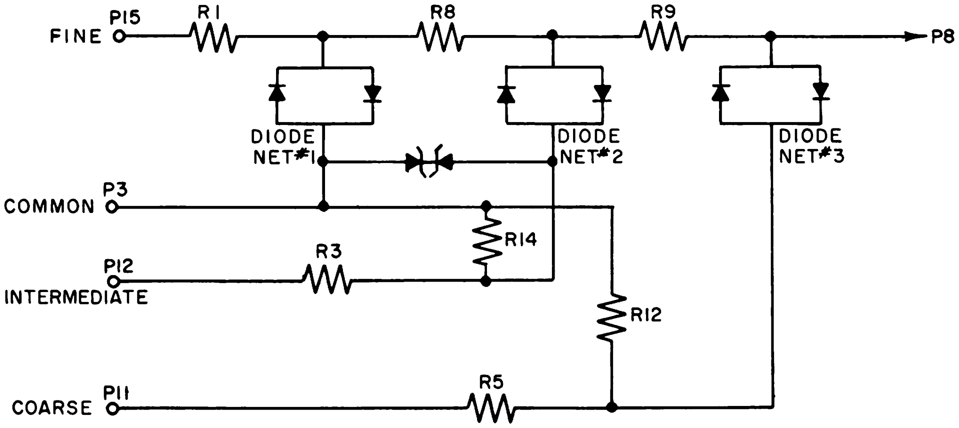

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Figure 5-4.—Simplified Signal Switching Circuit.

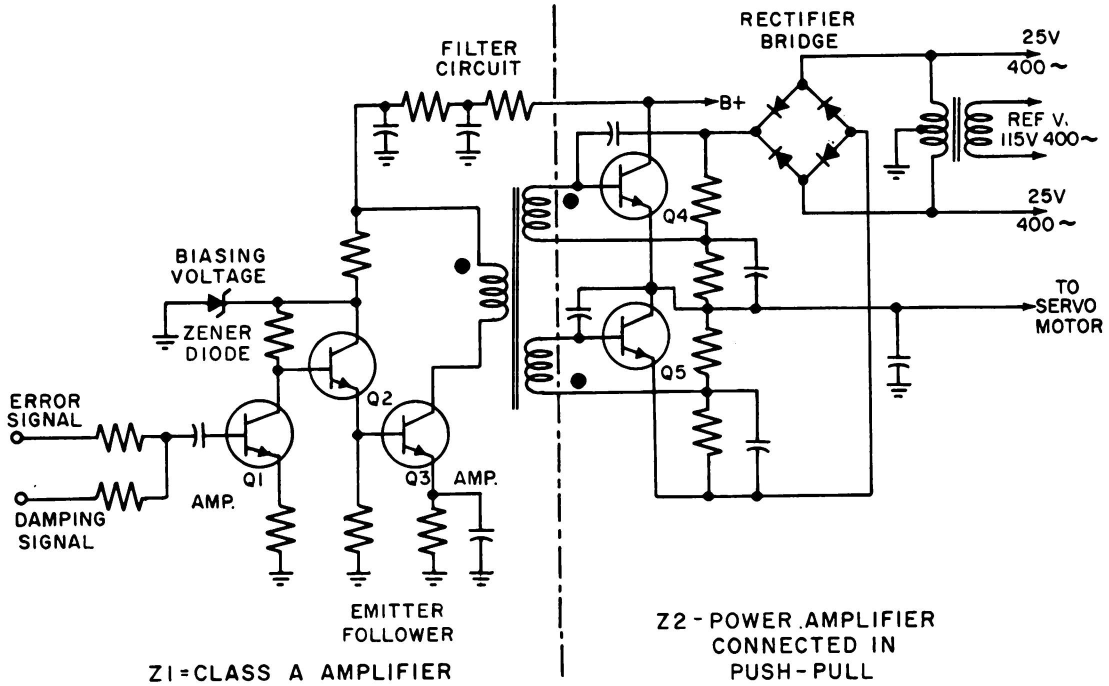

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Figure 5-5.—Servoamplifier.

The resolvers are conventional and provide two analog output signals representing the sine and cosine of the angular displacement of its rotor, Lyo in this case.

### Servo Module

A servo module contains all the electromechanical devices. In this servo these devices include the servomotor, tachometer, CTs, resolvers, and encoders. The physical description of modules was covered in the preceding chapter.

### Null Detector

The null detector (fig. 5-6), receives a null error signal from the transfer network and produces a d-c voltage which operates a relay whenever the servo error exceeds 20 minutes of arc. The relay, in turn, operates a remote NULL or NO-NULL indicator. When the relay coil is energized, normally open contacts are closed and supply 25 v. d-c to a green NULL indicator. When the relay is deenergized the contacts are closed and the 25 volts supplies a red NO-NULL alarm indicator. With this arrangement a NO-NULL indication will show when servo power is lost.

Current flow through the coil of the relay is controlled by the transistor Q5, (fig. 5-6). When Q5 is biased below cutoff the relay coil is deenergized. Since both the 25 v. supplies are positive, the potential difference across the coil is not sufficient to pick up the relay and there is a NO-NULL indication. When Q5 is conducting, the coil is energized through the circuit of Q5 and there is a NULL indication. The bias on Q5 is controlled by the conduction state of Q4. Q4 is biased to a nonconducting state by the voltage from the zener diode. Thus, when the servo is synchronized and the error signal is zero, Q4 is nonconducting. When the servo error exceeds 20 minutes of arc, the error signal will turn Q4 on and, therefore, shut Q5 off.

The error signal to the null detector is received from the servo transfer network and applied to three stages of amplification, which operate as a class A amplifier. The output from these three stages is coupled by a transformer to Q4.

Electrical/Electronic Modules

Since data flows between modules as electrical signals, the arrangement of the electrical/electronic components is more flexible than the electromechanical components. Therefore, all the electrical/electronic components are not located on a single module. For example, the blocks in figure 5-6A could represent four separate module types: preamplifier (Z1), amplifier (Z2), relay, and indicator. The same is also true of the circuit in figure 5-5, Z1 and Z2 could be separate modules.

## SWITCH DRIVER AND MOTOR CIRCUIT

The switch driver and motor circuit is a servo that relies on switching and gating circuits to control the position of its output. The switch driver circuit (fig. 5-7) can control as many as eight Haydon snap-slide switches. The driver circuit controls the position of the switches to any one of three positions. Each switch is driven by its motor which is a d-c split-field, series-wound motor. The direction of motor rotation is determined by the field winding energized, which, in turn, is determined by the driver circuit. A 28 volt position-control input signal to the driver circuit is applied to one of the three input pins. When one of these pins is selected, power is applied to the gating circuit of two of the silicon controlled rectifiers (SCRs). Motor control logic, (by the motor switching arrangement), completes the circuit through one of the gated SCRs to drive the switch to the ordered position.

Let's study the SCR gating circuits first. Obviously, a position control signal can only be on one input pin at a time. Assume the +28 volt position signal is on pin P8, position 1 command. This signal will gate SCRs 1 and 2. The gating circuit for SCR1 is from P6, which is the negative side of the line and is the common lead for the entire driver circuit, to connection C on SCR1 through R7 and R3 to P8. The gating circuit for SCR2 is from P6 to connection C on SCR2 through R9, CR1, and R3 to P8. The gating voltage is blocked from SCRs 3 and 4 by CR2.

Now assume the position signal is on P15, position 2 command. This signal will gate SCRs

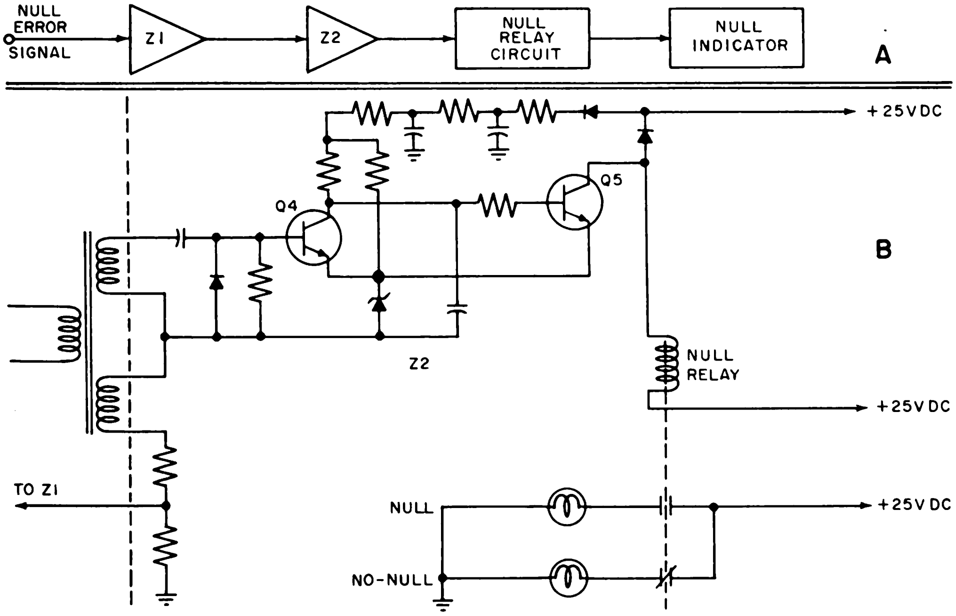

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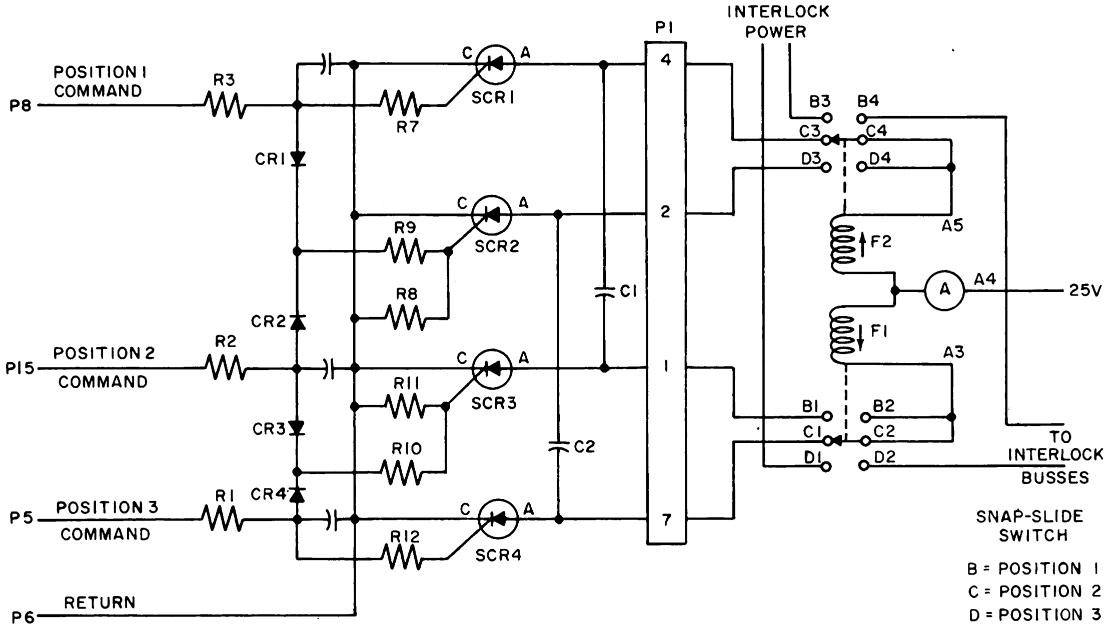
Figure 5-6.—Null Detector Circuit.



177.28

Figure 5-7.—Simplified Switch Driver and Motor Circuit.

2 and 3. The gating circuit for SCR2 is from P6 to connection C of SCR2 through R9, CR2, and R2 to P15. The gating circuit for SCR3 is from P6 to connection C of SCR3 through R10, CR3, and R2 to P15. The gating voltage is blocked from SCR1 by CR1 and from SCR4 by CR4.

If the position signal is on P5, position 3 command, SCRs 3 and 4 will be gated. The gating circuit for SCR3 is from P6 to connection C on SCR3 through R10, CR4, and R1 to P5. The gating circuit for SCR4 is from P6 to connection C on SCR4 through R12 and R1 to P5.

Thus in summary: if position 1 is commanded SCRs 1 and 2 are gated; if position 2 is commanded, SCRs 2 and 3 are gated; and if position 3 is commanded, SCRs 3 and 4 are gated. The circuit to the motor fields will be completed through one of the gated SCRs. The selection of which SCR is determined by the motor switch position.

The gate signal to the SCRs indicates the ordered switch position. The motor switch position indicates the present position of the switch. Assume the switch is in position 2 and receives a command to move to position 1. The position command is to P8 and provides a gating voltage to SCRs 1 and 2. The circuit to the F2 motor winding is completed through the motor switch contacts C4 and C3 to SCR1 and then to the return side of the line P6. Note that this is the only complete circuit through the motor fields. Completion of this circuit causes the motor to drive in a counterclockwise direction and to snap the switch to position 1. With the switch in position 1, the circuit to the motor fields is open and the switch will remain in this position until a command to a new position is received in the driver circuit.

Assume the switch is in position 1 and receives a command to move to position 3. This position command signal will gate SCRs 3 and 4. The circuit to motor field F1 is completed through motor switch contacts B2 and B1, and SCR3. The motor drives the switch to position 2, which will open the circuit to SCR3. In position 2 the circuit for motor field F1 is completed through motor switch contacts C2 and C1, and SCR4. The motor will continue to drive the switch to position 3 where the circuits to both SCR3 and SCR4 are open. The switch will remain in this position until ordered to a new position.

The commutating capacitors C1 and C2 prevent oscillations from occurring when the driver circuit is controlling more than one snap-slide switch. Control circuits to the additional switches are connected in parallel at P1. The interlock circuits energize an interlock device to prevent the motor from driving the switch past its limits of operation.

## ANALOG COMPUTING SERVOS

The servos we described were relatively simple, their job of positioning a load as dictated by an uncomplicated input signal is accomplished in a straightforward manner. The analog computing servos perform electrical or mechanical operations on the input quantities that are similar in nature to mathematical operations. The solution to the problem is found by measuring the output quantity. The FCS uses the following basic analog operations: generation, modification, and monitoring. Generation refers to the conversion of a mechanical or physical quantity into a proportional analog voltage. The analog quantities commonly converted are position and velocity. Examples of electromechanical converters are synchros, resolvers, and tachometers. You are familiar with these components.

Modification refers to the various operations an electrical signal undergoes to obtain a desired result. This modification may be necessary to restore an attenuated signal (amplification—a form of multiplication), to make the signal phase sensitive (modulation and demodulation, which in essence is assigning a mathematical sign, positive or negative, to a signal as determined by its phase or polarity), to add various analog signals algebraically (summation), or to remove extraneous signal components (filtering). These operations account for the major portion of the analog modules.

Monitoring refers to checking the electrical level of an analog signal and activating status circuits to indicate the level. A typical monitoring device is the null detector. One use of the null detector in the FCS is to energize a console lamp when its input signal is reduced to approximately zero. We covered a null detector circuit earlier in the chapter.

## MODIFYING MODULES

There are four broad classifications of modifying modules: amplifying, modulator-demodulator, network and transformer. There are different types of modules in each category that perform the same function. The variations are due to such factors as: the level and frequency of the reference and signal voltages and the desired characteristics of the output voltage. But the basic function of the module circuits are similar, therefore, a description of a 400 Hz modulator can be readily applied to a 800 Hz modulator. We will describe representative modules. The discussion will be functional in nature as it is assumed you know the theory of basic electronic components and circuits.

### Standard A-C Amplifier

The standard a-c amplifier (fig. 5-8) satisfies many of the amplification needs of FC circuits. It is a class A amplifier consisting of three stages. The power, bias, and feedback inputs to the amplifier vary according to its use and adapt the amplifier to its applications.

The base of Q1 is biased at a positive potential determined by external circuitry. The base of Q2 is biased at +14 volts by the voltage divider consisting of R3, R1, R2, CR1, R5, and R11. The base of Q3 is biased at a positive potential determined by the voltage divider made up of R6, R8, CR3, R9, and R11. This bias potential varies depending on the load placed on pin P1.

An input signal at pin P5 will affect the conduction of Q1. A positive signal will increase conduction while a negative signal will reduce conduction. The inverted amplified signal is coupled to Q2 through R2 and CR1. The signal is amplified and inverted by Q2 and coupled to Q3 by R8 and C3. The output of the amplifier which appears at pin P8 is 180 degrees out of phase with the input while the output at pin P1 is in phase with the signal. The output, which may or may not be inverted is an amplified duplication of the input signal. The RC network in the collector circuit of Q2 provides high-frequency rejection.

### Summing Amplifiers

Summing amplifier modules perform various functions some of which are not implied by the name. We will describe the implied function of summing analog voltages and then briefly discuss other uses. Although a summing circuit output can be considered as a summation of voltages, the real job of the circuit is to determine the algebraic sum of variable FC quantities, which are represented by analog voltages. A scale

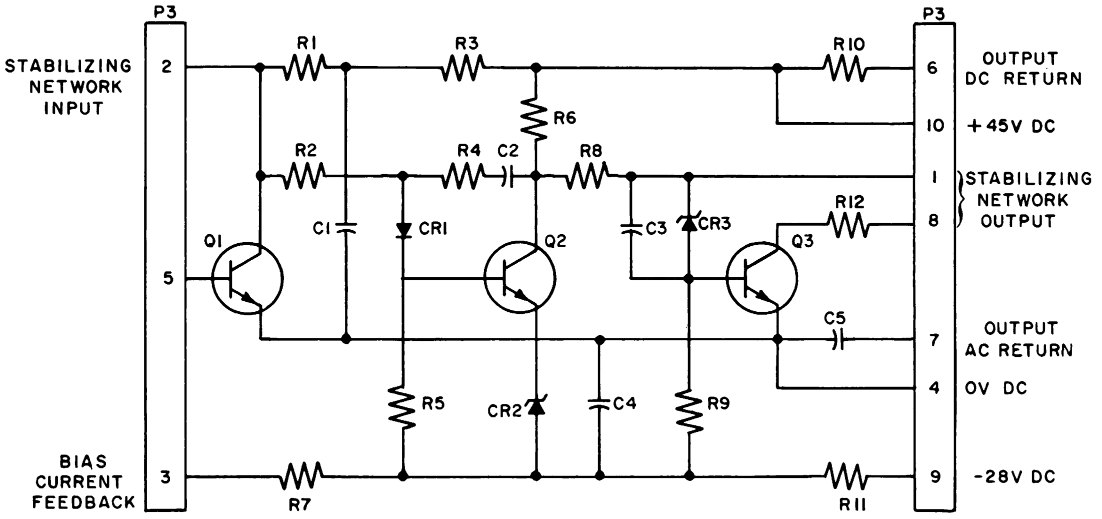


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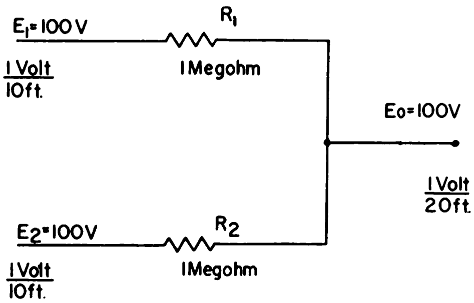
Figure 5-8.—Standard a.c. Amplifier.

factor is assigned to these voltages and must be considered. Figure 5-9 shows a two-input summing network with no load. Each input (100 v) represents 1000 feet. $E_o$, the output voltage, is 100 v and represents the sum of the inputs, 2000 feet. You can see that the scale factor of the output is now one-volt/20 feet. And with any load at all at $E_o$ (the input of a summing amplifier, for example), not only will the scale factor change more drastically but the voltage at $E_o$ is greatly attenuated compared to the inputs.

Often the inputs to a summing network are not scaled the same. Suppose $E_1$ of figure 5-9 was scaled at one volt/10 feet but $E_2$ was scaled at one volt/20 feet and we wanted to sum 1000 feet at each input. The E1 input would be 100 v and the E 2 input 50 v. Yet each represents the same quantity, 1000 feet, and must have the same effect on $E_o$. To rescale E2, R2 can be changed to one-half megohm so that the 50 v through one-half megohm will have the same effect as 100 v through one megohm.



12.86

Figure 5-9.—Scale Factors in a Summation Circuit.

A summing circuit used by itself is not very accurate, some of its drawbacks are:

1. The input voltages are attenuated in the circuit.
2. The parallel legs interact with one another.
3. A change in the output load will produce a scaling error.

Since the analog voltages represent quantities the summing circuit must be extremely accurate. The addition in the circuit of an amplifier (fig. 5-10), that provides almost unity negative feedback will prevent loading and thus permit summation without a scale change. The amplifier in the circuit is the standard amplifier we just described. The output of the summing circuit, eg, is the input to the amplifier. The amplifier output Ef is impressed across the feedback resistor Rf. Hence eg is equal to the sum of the input voltages we wish to add minus the feedback voltage. Therefore, when Ef is equal and opposite to the sum of E1 and E2, the signal voltage to the amplifier will be nulled. In this condition the

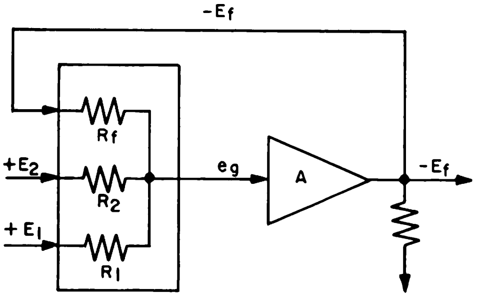


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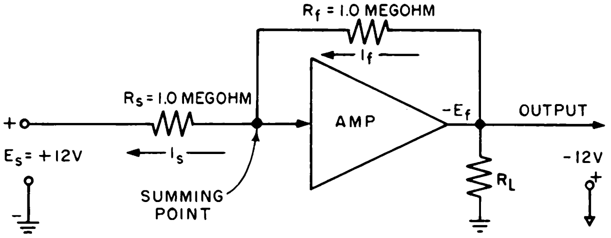
Figure 5-10.—Summing Amplifier.



12.297
Figure 5-11.—Sign Reversing Loop with Unity Gain.

output of the summing loop, -Ef, will be equal to the sum of E1 and E2.

The amplifier has a high gain to ensure accuracy. The overall loop gain is proportional to the ratio between the feedback resistor and the input resistors. Thus the loop can be designed to provide summation without a scale change or, where desired to provide a scale change. Since variations in the loop are determined by circuits external to the amplifier, the standard amplifier can be used. Where more than two analog voltages are to be added, additional parallel legs are used. There are as many legs as there are signals to be added, plus an answer or feedback leg.

The feedback principle isolates the output of the summing loop from its input circuit and automatically compensates for fluctuations in the power supply. Thus a summing amplifier, which includes a summing circuit and a standard amplifier, can perform various functions that will modify the output signal without affecting the input signal. The summing amplifier in figure 5-11 can reverse the sign of an analog voltage without changing any other characteristic of the voltage. By changing some of the components in the input and/or feedback circuits the summing amplifier can be made sensitive to a particular frequency and to attenuate all other frequencies. Or it can be designed to introduce a fixed phase shift or to compensate for an undesirable phase shift between the signal generator and the load. Other names used for summing amplifiers in the analog servo field are computing, operational, buffer, isolation and feedback.

### Modulator-Demodulator

We will describe a module that can be used as a modulator or a demodulator depending on its application. In either application an 800 Hz reference voltage is connected to the primary of T1, (fig. 5-12). When the module is used as a modulator, the input on pins 12 and 16 is a d-c potential varying in amplitude and polarity. The modulator output is taken from T2 on pins 8, 17, 5, 7 and 6. When this module is used as a demodulator, the input signal is an 800 Hz signal applied to two or more of pins 8, 17, 5, 7, and 6. The demodulator output is on pins 12 and 16.

We will discuss modulator application first. The input is a d-c voltage whose polarity indicates the direction of the error and whose amplitude represents the magnitude of the error. We need to convert this signal to an a-c signal whose phase and amplitude represent the signal direction and magnitude. The phase of the a-c signal is measured with respect to the 800 Hz reference voltage on T1. There are five conditions which may exist:

Case

1. The input signal is zero.
2. The input signal is positive and the reference voltage is in its positive half-cycle.
3. The input signal is positive and the reference voltage is in its negative half-cycle.
4. The input signal is negative and the reference voltage is in its positive half-cycle.
5. The input signal is negative and the reference voltage is in its negative half-cycle.

In case 1, the d-c input signal is zero and the output should be zero. There are two complete circuits for the reference voltage. One path is from terminal 9 of T1, (negative side, the dot in the figure indicates a positive potential), down through the 7-6 winding of T2, through CR2 and R2 to terminal 10 of T1. The other path is from terminal 9 of T1 up through the 7-8 winding of T2, through CR1 and R1 to terminal 10 of T1. The current through the two sections of the T2 winding are equal and opposite. Therefore, no voltage will be developed in the primary winding of T2 and the output will be zero. On the next half-cycle of the reference voltage the circuit operates in a similar manner except that current flows through the 11, 10 and 9 winding of T2.

In cases where the d-c input voltage on pins 12 and 16 is not zero, this voltage is divided equally between R1 and R2, and controls the amount of current in each loop. In case 2, pin 12 is positive with respect to pin 16 and there will be more current through CR1, R1, winding 10-9 of T1 and winding 7-8 of T2 than through CR2, R2, winding 10-9 of T1 and winding 7-6 of T2. This unbalance of current through the two loops will induce a voltage in the primary of T2. For case 3, the same unbalance of current occurs but it is in the other two loops. The large current is through CR3 and R1 and the small current through CR4 and R2. Again a voltage is developed in the primary of T2 but opposite in phase to case 2.

For cases 4 and 5 the d-c input polarity is now negative at pin 12 with respect to pin 16. For case 4, a large current passes through CR2, R2, winding 10-9 of T1 and winding 7-6 of T2. The small current passes through CR1, R1, winding 10-9 of T1 and winding 7-8 of T2. The current unbalance induces a voltage into the primary of T2 that is opposite in phase to that induced in case 2. In case 5, the large current passes through CR4, R2, and winding 10-11 of T1 and winding 10-11 of T2. The small current passes through CR3, R1, winding 10-11 of T1 and winding 10-9 of T2. The voltage induced in the primary of T2 due to the unbalance is opposite in phase to that developed in case 3.

The output is an a-c signal voltage whose frequency is the same as the reference voltage and whose phase, measured with respect to the reference voltage, is determined by the polarity of the d-c signal voltage and whose magnitude is determined by the magnitude of the d-c signal voltage. Thus the a-c signal output represents the same data as the d-c signal.

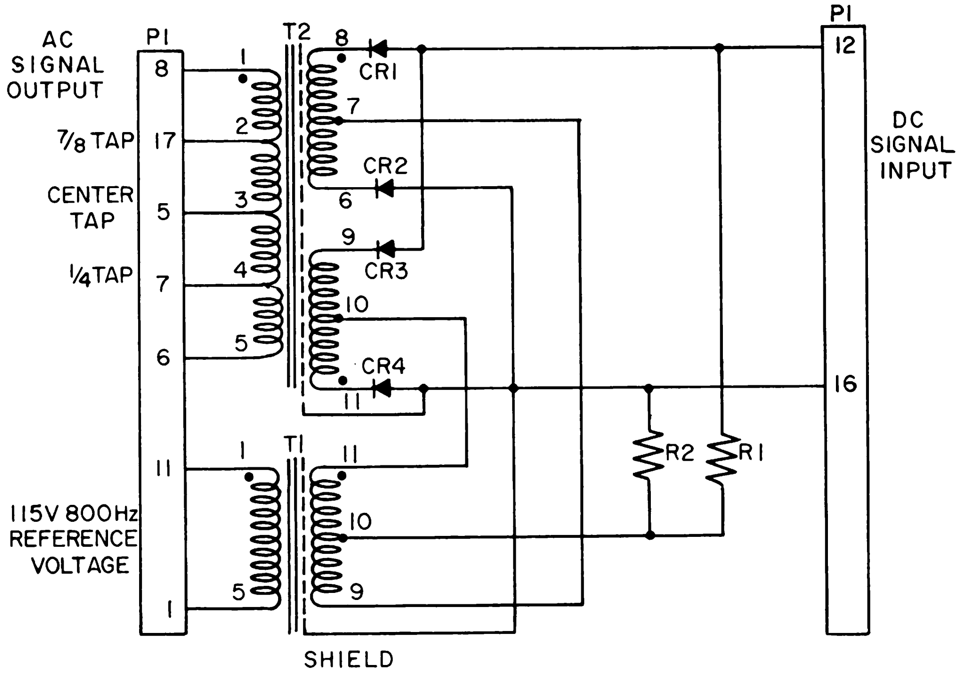


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Figure 5-12.—Simplified Modulator Circuit.

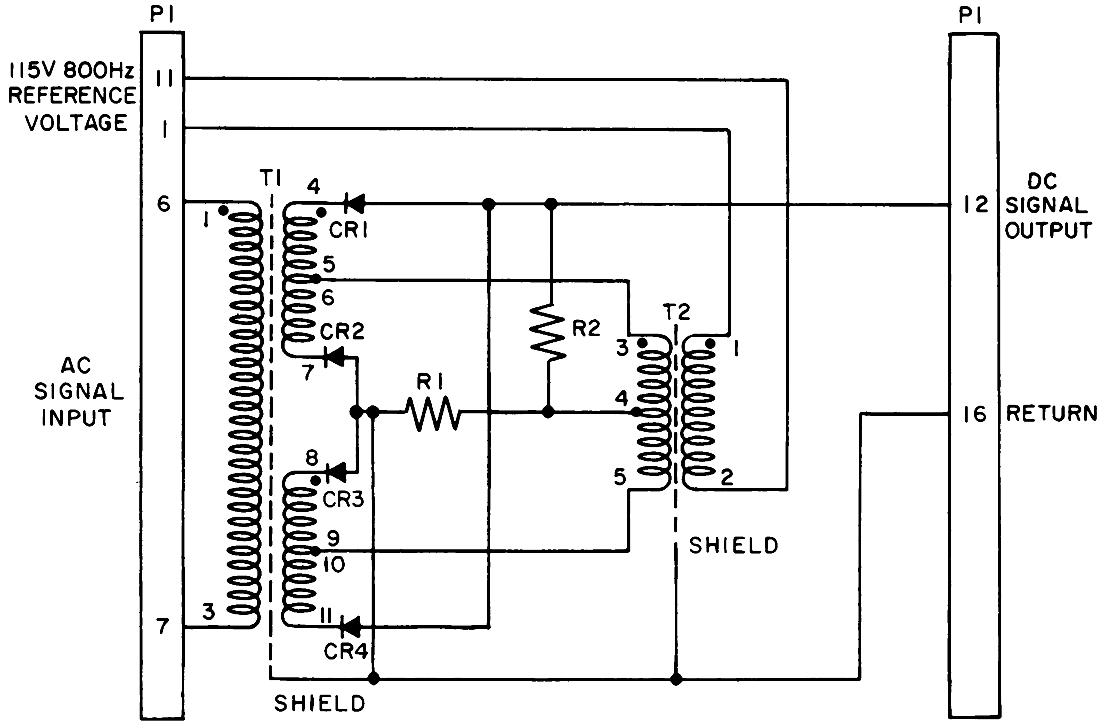

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Figure 5-13.—Simplified Demodulator Circuit.

Demodulator Operation

When the module is used as a demodulator (fig. 5-13), the signal input on pins 6 and 7 is an a-c 800 Hz voltage whose phase indicates the direction of the error and whose magnitude indicates the amplitude of the error. The phase of the a-c signal is measured with respect to the reference voltage on T1. There are four possible signal-to-reference voltage relationships:

Case

1. Signal and reference voltages, both on the positive half-cycle, are in phase.
2. Signal and reference voltages, both on the negative half-cycle, are in phase.
3. Signal voltage (on its negative half-cycle) and reference voltage (on its positive half-cycle) are 180 degrees out of phase.
4. Signal voltage (on its positive half-cycle) and reference voltage (on its negative half-cycle) are 180 degrees out of phase.

The output signal is a d-c voltage whose polarity indicates the direction of the error and whose magnitude indicates the amplitude of the error. The signal is developed by the voltage drop across R1 and R2. If the input signal is zero, the voltage developed across R1 is equal and opposite to the voltage developed across R2, resulting in a zero output signal on pins 12 and 16.

In case 1, the voltages in winding 10-11 of T1 and in winding 4-5 of T2 are in phase, (additive) and will cause current to flow through CR4 and R2. There is also a current flow through CR3 and R1 originated by the voltages in winding 4-5 of T2 and winding 8-9 of T1. But these voltages are out of phase (subtractive) and the current through R1 will be less than that through R2. In case 2 the additive current will flow through CR1 and R2. The subtractive current will flow through CR2 and R1. In cases 1 and 2, the current flow through the resistors is in the same direction (full-wave rectification), and the current passing through R2 is greater than that through R1. Consequently, the voltage drop across R2 is larger and determines the polarity of the output voltage. The magnitude of the output voltage is the resultant of the two voltages applied to R1 and R2 in series.

In case 3, the additive current passes through CR3 and R1, while the subtractive current passes through CR3 and R1. In case 4, the additive current passes through CR2 and R1, while the subtractive current passes through CR1 and R2. Thus for these two cases the voltage dropped across R1 will always be greater than that dropped across R2. Therefore, the polarity of the d-c output signal is now determined by the voltage developed across R1. The magnitude of the d-c output is the resultant of the two voltages dropped across R1 and R2.

## TRANSFORMER MODULES

Transformer module circuits are conventional and so do not require an explanation here. These modules perform standard transformer operations such as stepup, stepdown or inversion of voltages, isolation of sections of a circuit from other parts of the circuit, and the generation of simulated signal voltages for test purposes.

## NETWORK MODULES

Network modules are used to couple signals between other modules and in so doing may modify the signal level or phase, select the appropriate signal (fine or coarse) supplied to the amplifier, determine and limit the stabilization signal supplied to the amplifier, and perform passive summing of signals. A transfer network module was covered earlier in this chapter.

## CHAPTER 6

# DIGITAL COMPUTERS

Digital computers are used extensively in the FBM Weapon systems. To understand the operation of the system in general, and the computer portion in particular, it is necessary to have a basic understanding of computer functions, circuitry, terminology and applications. Basic Electronics, NavEdTra 10087-C, Digital Computer Basics, NavEdTra 10088-A, and Mathematics, Vol. 3, NavEdTra 10073-A, present a basic coverage of the purpose, operation, and theory of computers, together with some of the terminology peculiar to them. Review and study of these basic coverages will aid in understanding the material covered in this chapter.

### INTRODUCTION

A definition of a computer is any device capable of accepting information, applying mathematical operations to that information and obtaining useful results of these operations.

The ability to calculate is built into the computer by proper combinations of relatively simple circuits. A computer also can hold information by storing it in memory banks. This information, is retrievable when required for testing or operation. In most computers, information is stored by magnetic means, and is kept for varying periods of time—from a few milliseconds to years—depending upon what use is to be made of it.

When a computer performs an operation, it manipulates data that has been placed into it. Its input consists of data that must be "read" and automatically translated into a computer's language—electronic pulses or no-pulses.

Since the digital computer uses coded numbers, it follows that any information fed to the machine must be changed from plain language into a coded number form.

The type of coding normally used in digital computers is based on the binary number system, as explained in Basic Electronics, NavEdTra 10087-C.

### MAJOR UNITS

All digital computers can be broadly broken down into the input-output unit, the memory unit, the arithmetic unit, and the control unit as shown in figure 6-1.

The input-output unit is just what the name implies; it takes in and puts out information. This may be fed into and taken from a computer by any of several means, a few methods are:

1. Punched cards (most Navy paychecks have perforations which, when fed into a computer, identify the check with the issuing activity and with the person to whom the check was issued).
2. Magnetic tape (similar to the tape used in audio tape recorders).
3. Special purpose devices (missile guidance systems, or tactical display consoles).

All of these and many others may be fed individually (or in combinations) to a computer

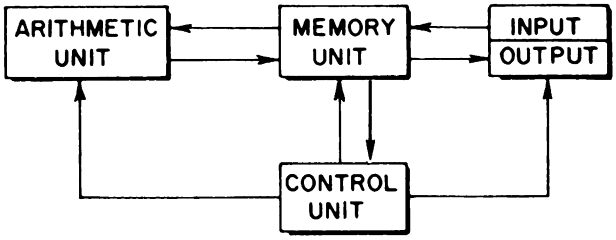

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Figure 6-1. — Fundamental Units of a Digital Computer.

which is built to accept that type input. They all do the same thing—feed pertinent data to the computer so that a logical solution to the problem may be obtained.

The output unit translates the result of the computer's operations into a visual indication, or into some other form that is readily usable. The output of a computer may operate a relay or a light, or it may be used to position some mechanical device.

The memory unit stores information until the control unit asks for it. Data fed to the computer will be directed to and stored in the memory unit. Such data includes INFORMATION and INSTRUCTIONS. Instructions tell the computer what operations to perform, the order in which to perform them, and what to do with the results. Information, on the other hand, deals mainly with the quantities involved in calculations. The velocity of light is the upper speed limit at which a digital computer can pass data from one unit to another. To get around this limitation, data is fed into, through, and out of a computer in parallel form rather than serial form.

In serial form, the individual instructions and information bits are fed step after step, one bit at a time. This is a comparatively slow process, but may be accomplished with few and simple circuits. Parallel input permits a number of bits to be fed at the same time, resulting in a much faster rate. More complex circuitry is required for parallel inputs. In a practical computer, instructions and information may be fed into the computer at the rate of 3 million bits per second, using the parallel input. Rates as high as 50,000 bits per second are common, using serial feed systems.

The arithmetic unit is the calculating unit. It contains circuits that are simple in both theory and operation. It performs mathematical operations—addition, subtraction, multiplication, and division—by performing logical operations. It must be remembered that all mathematical calculations dealing with numbers take some form of one or more of these basic operations. For instance, squaring a number is merely a special form of multiplication; extracting a square root involves all four operations in a special order. Similarly, an exponential curve is simply the result of many instantaneous values computed by arithmetic means.

By comparing data quantities against each other, the arithmetic unit is able to make logical decisions. For example, it can determine the proper weapon line by considering target location, ship location, wind velocity and direction, ballistics information regarding the particular weapon, and other factors that have been fed to it, and then provide a "yes or no" answer to specific questions. The solution to a given problem is sent from the arithmetic unit to the memory unit where it remains in storage until needed for further calculations, or until otherwise routed by the control unit.

The control unit of a computer ties all parts of the computer together, causing them to function as an integrated system. Its functions are the same as for the control unit of any system: it commands complete control over every operation the computer performs.

## LOGIC FUNCTIONS AND MODULES

The language of digital computers is binary which is a convenient means of encoding numbers, letters, and characters. The five essential units of digital computers "talk" with one another in the same electrical language. Data and instructions are encoded into the presence or absence of electrical pulses, as indicated in figure 6-2. Here the decimal symbol 3 is encoded in its binary form—no pulse, pulse, pulse.

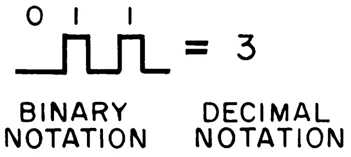

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Figure 6-2.—Digital Computer Language—A voltage Pulse is a Binary "1" and No Pulse is a Binary "0".

As stated previously in this chapter, many of the basic circuits in digital computers are logic circuits which provide "yes or no" answers to specific questions. These circuits may be gates which are either conducting or cut off, with the output at one of two voltage levels. Each of these voltage levels or pulses may be considered as being positive or negative with respect to the other. Normally, the output levels are referred to as digital 0's and digital 1's. Insofar as the circuitry is concerned, it is possible to use either voltage level to indicate either digit. Therefore, it is essential to the understanding of basic logic circuits that some distinction be made regarding the system of logic to be used in any specific application.

LOGIC.—The term POSITIVE LOGIC is used to denote circuitry in which a positive level of signal voltage is used to activate the gate circuit. This is normally extended to include the idea that in a completely positive logic circuit, inputs of a relatively positive level will produce relatively positive output levels.

NEGATIVE LOGIC circuits operate in the same manner as positive logic circuits, except that negative inputs are used to activate the gate circuit.

COMPUTER SYMBOLS.—Many of the basic circuits used in computers are conventional circuits applicable to general electronics. Other circuits are peculiar to logic applications. In this chapter, explanation of each basic circuit will be accompanied by a block diagram representation of the circuit, as well as a simplified schematic of the circuit.

## LOGIC FUNCTIONS

Logic functions define the relationship of a dependent condition or variable to the independent condition in a logic expression. Consider the expression "Lamp A lights if switch B is closed." The phrase "lamp A lights" is the dependent condition while the phrase "switch B is closed" is an independent variable. Hence the lighting of the lamp depends on the position of the switch. In a digital computer using binary notations the variable can have only two possible states. This fact does not limit the number of variables in an expression but it does limit the variations a variable can take.

Since events in a computer are represented by binary bits the nature of the events are known. Therefore, this concept pertains to the occurrence or nonoccurrence of an event and not to its nature. The events represent a statement of a problem, such as: is the input an address instruction word; is the program completed; is the target within the limits of the weapon; and if so, is there a solution? A computer applies well-defined symbols to describe the events and operates on the symbols in a mathematical manner. Thus there appears a branch of pure mathematics concerned with logical statements.

There are three basic logic circuits in the computer that form the model for the mathematics. These are called the "and," the "or," and the "not" logic circuits. In logic circuit diagrams the "and" operation is symbolized by the mathematical multiplication sign, ("x", ".", or "AB"). The "or" operation is symbolized by the addition sign, ("+"). The "not" operation is symbolized by a bar over the quantity, ($\overline{B}$). Since this is a special form of mathematics, the symbols have special meanings. Hence on a logic diagram "AB" should be read as "A and B", not as "A times B", while "A + B" should be read as "A or B" not as "A plus B", finally $\overline{A}$ should be read as "not A". The symbols are convenient, but do not confuse their meanings.

Now let's consider how the rules used to operate on the symbols were arrived at. We will use simple situations out of a fire control problem to demonstrate the logic circuits. Any bistable component can be used in a logic circuit but we will use only relays and lights for clarity of explanation.

We will start with a "not" circuit (fig. 6-3A). The computer must determine the occurrence or nonoccurrence of an event which we will call event A. If, and only if, there is no error in the solution of the fire control problem will event A occur. The computer will check its solution; if there are no error signals then event A has occurred, and the relay in the figure will be energized by the relay switch. The relay will open the switch in series with the light. (The light in the computer indicates a no-solution condition.) If event A does not occur, there are errors in the computer and there is no correct solution. Then there is a not A ($\overline{A}$) event in the computer and the relay switch is opened. The relay drops out and the circuit to the no-solution light is completed. You can see from this simple "not" logic circuit that event A and event $\overline{A}$ can not exist simultaneously. That is, they are incompatible, A is the complement of $\overline{A}$. If event A occurs, then event $\overline{A}$ can not occur, thus either the light is on or off.

The "not" logic function is also referred to as the "inversion" function. Inverting a quantity, expression, or variable forms its one's complement. Since 1 and 0 are the complement of each other in the binary numbering system,

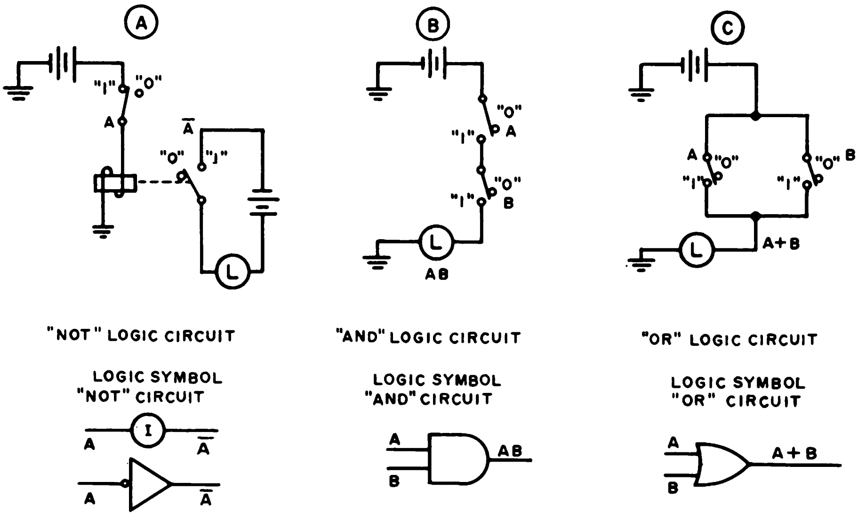

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Figure 6-3.—Basic Logic Circuits.

the complement of a binary number is formed by changing every 1 to 0 and every 0 to 1. For example, the complement of binary number 10100 is binary 01011. When complementing an expression each quantity and each sign must be changed. The FC digital computers use the one's complement arithmetic method. We will discuss this when we cover binary arithmetic.

Now let's consider the "and" logic circuit (fig. 6-3B). This circuit considers two separate events which we will call event A and event B. The output of the circuit (AB) will occur if, and only if, both event A and event B occur. Assume event A represents the computer has calculated target range and event B represents the range is within limits of the weapon. You can see from the logic circuit that if both events do not occur, then event AB can not occur and the indicator light will be off. The nature of the two events, (range calculated and range within limits) are different, but we are concerned only with their occurrence and we can operate logically with them in one circuit.

Now we will consider the "or" logic circuit (fig. 6-3C). This circuit considers two events which we will call event A and event B. In the output circuit, event A+B will occur if, and only if, at least one of the events A or B occurs. The presence of event A operates switch A and the presence of event B operates switch B. You can see from this simple "or" logic circuit, if event A or event B occurs, event A+B will occur and the light will be on. Therefore, both events control the light and both switches can supply voltage to the lamp simultaneously.

Notice that the output of the "and" circuit and the output of the "or" circuit is an event in itself. Therefore, more than two events can be operated on by means of "and", "or" circuits. For example, AB "and" C equals (AB)C, while (AB)C "and" D equals (ABC)D. The statement (AB)C can be rearranged to A(BC) for the two statements are mathematically equal. Thus the events in an "and" circuit can occur in any random order and the circuit will still operate logically. Similarly, events A+B "or" C equals (A+B)+C, while (A+B+C) "or" D equals (A+B+C)+D. We would continue this process until all the events involved in the problem have been considered.

A combination of a "not" circuit and an "or" circuit is referred to as a "nor" logic circuit. A "nor" function is produced by inverting the output of an "or" circuit, (fig. 6-4A). One way to express a "nor" circuit on relays A and B is:

$$f(L) = \overline{A+B}$$

which says that "The circuit to light L in the diagram is a closed circuit unless either relay A or B is operated."

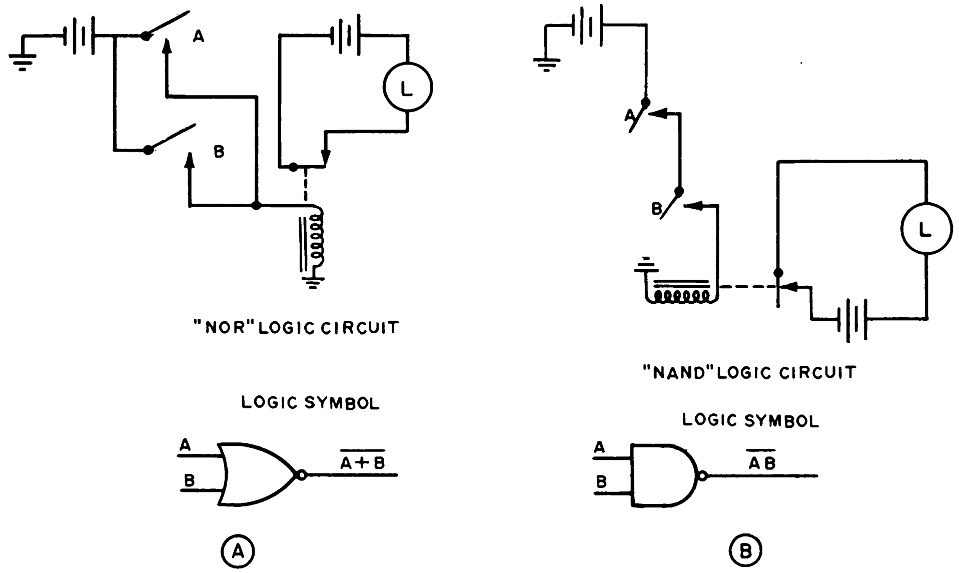

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Figure 6-4.—The "NOR" and the "NAND" Logic Circuits.

A combination of a "not" circuit and an "and" circuit is called a "nand" logic circuit. A "nand" function is produced by inverting the output of an "and" circuit, (fig. 6-4B). One way to express a "nand" circuit on relays A and B is:

$$f(L) = \overline{AB}$$

which says that "The circuit to light L in the diagram is complete unless both relay A and relay B are operated."

Symbology

Fire control prints employ dual symbology. Dual symbology identifies the various functions that can be performed by a logic element. An open circle (o) indicates a logic "0", the lack of an open circle indicates a logic "1". An open circle at the input of any logic symbol indicates that a logic "0" is the state of the signal required to satisfy the function of the logic element. A logic gate shown with an open circle at the output and an absence of open circles at the input indicates that a logic inversion takes place within the gate.

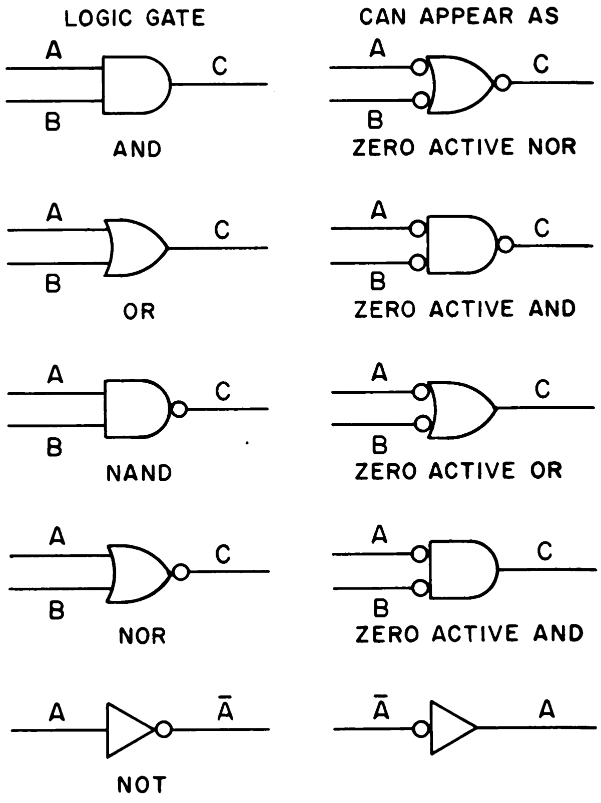

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Figure 6-5.—Basic Block Element Symbols.

Figure 6-5 illustrates the two distinctive shape symbols of each of the basic block elements. The symbol used in fire control prints will depend on the desired inputs and outputs of the logic element in its active state.

To better understand the use of dual symbology, the operation and evolution of an "exclusive or" circuit from conventional to dual symbology is presented in the following paragraphs. Figure 6-6A shows a combination of conventional logic symbols that can be used to form an "exclusive or" circuit. An "exclusive or" circuit will produce an output signal if an input signal exists at A (but not at B) or at B (but not at A). No output signal is produced if no input signals exist or if input signals exist at both A and B.

Simultaneous input signals at A and B will produce a logic "1" from gate X. The logic "1" from gate X will produce a logic "0" at the output of gate Z. If neither A or B input signals are present, gate Y will be qualified (logic "1" output) producing a logic "0" at the output of gate Z. If input signal A is present, but not input signal B (or vice versa), both gates X and Y will have outputs of logic "0" producing a logic "1" from gate Z.

Thus gate Z requires two logic "0" inputs to produce a logic "1" output when the circuit is active. Changing the symbol of gate Z (NOR) to its alternate, (ZERO ACTIVE AND) has no effect on circuit operation; see figure 6-6B. When the revised circuit is active, gate Z still requires two logic "0" inputs to produce a logic "1" output.

The next step is to change gates X and Y to their alternate symbols; see figure 6-6C. The inputs to gates X and Y necessary to produce a logic "1" at the output of gate Z have not changed, however; it is now obvious that both gates X and Y require at least one logic "0" input to produce the desired output (logic "1") at the output of the circuit.

## LOGIC MODULES

The logic circuits and networks in the digital computer consist of combinations of digital modules. Generally, each type module performs a logic function. Hence, the basic logic circuits are the building blocks of the modules. We will discuss some of these basic circuits before we cover the modules themselves. The building block common to most of these modules is the NOT gate.

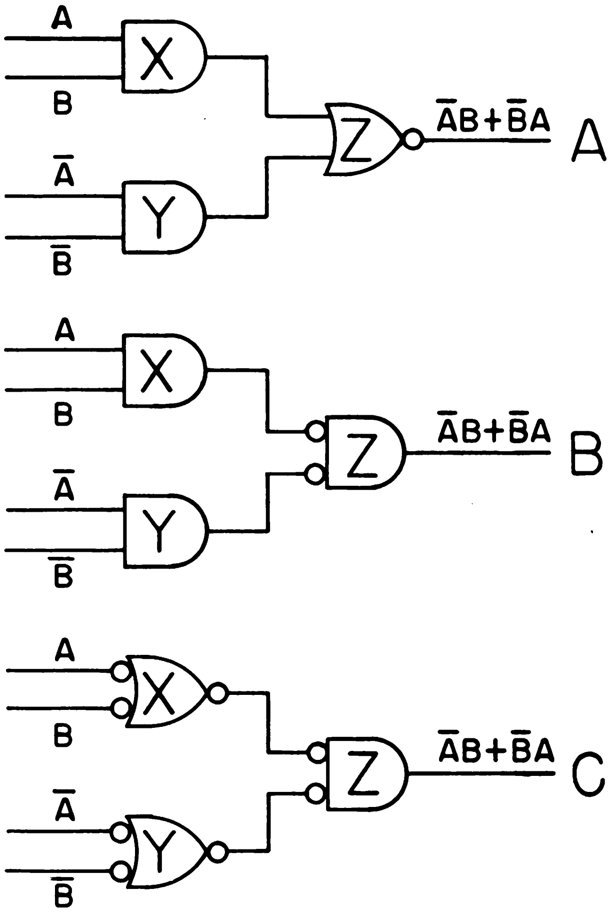

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Figure 6-6.—"Exclusive Or" Circuits.

### NOR Gate

The NOR gate (fig. 6-7) has a diode OR circuit followed by a NOT circuit. This particular NOR gate has three inputs to its OR circuit, which consists of the diodes CR1, CR2, and CR3. When a logic "0" $(-10^V)$ is applied to all the diodes, none of them conduct and Q1 is forward-biased by the negative voltage on its base which is due to less resistance of $R_1 + R_2$ compared to R. With Q1 conducting, a logic "1" $(0^V)$ appears at the output. Thus, the NOR gate has inverted the logic input. If a logic "1" is applied to any one of the input diodes, that diode is forward-biased, reducing the voltage at the junction of $R_1$-$R_2$. This places a positive potential on the base of Q1 and stops it from conducting. As a result of a logic "0" $(10^V)$ appears at the output.

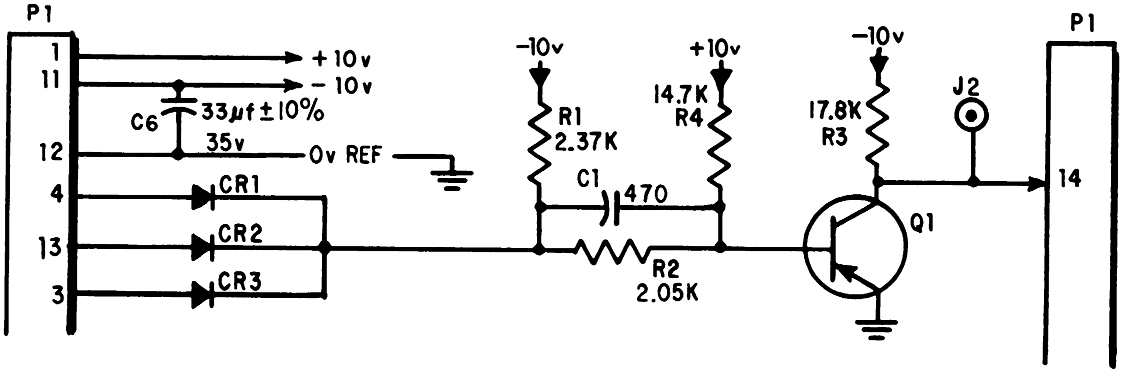

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Figure 6-7.—The "NOR" Circuit.

AND Gate

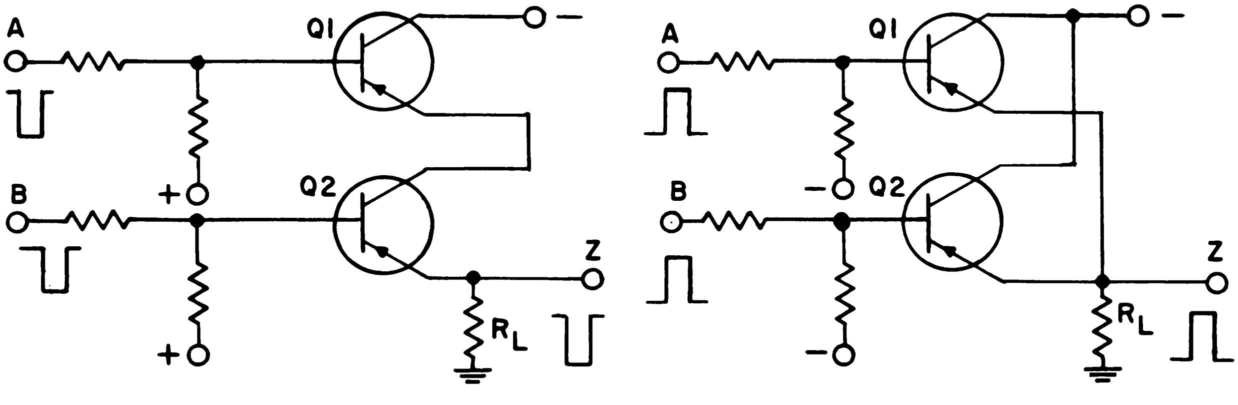
The AND gate electrically performs the AND logic function. The circuit in figure 6-8A is a negative logic AND circuit. With no signal applied, each transistor is biased to cut off by a positive voltage and the output is a logic "0" at terminal Z. A negative signal, which is equal to a logic "1", applied to one of the bases will drive that transistor into conduction. All the transistors must be conducting to shift the output to a logic "1" level. If one of the transistors remains cut off, there is no current path through the series connected emitter-collector circuits.

In figure 6-8B, a positive logic AND gate is shown. With no signals applied, the transistors are biased to saturation conduction and the potential at Z is negative representing a logic "0". A positive signal to the base will cut off the transistor. Since the transistor circuits are tied together in parallel, both transistors must be cut off in order to shift the output of the gate to a more positive potential to provide a logic "1" ($0^V$) output.

AND gates in most computers do not have a unique physical location. That is they do not have separate modules. It is used with other logic circuits and is part of their module.

Flip-Flop Circuits

Basically, a FF consists of two NOR circuits, (fig. 6-9). The output of these circuits feedback



A. NEGATIVE LOGIC

B. POSITIVE LOGIC

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Figure 6-8.—The "AND" Circuit.

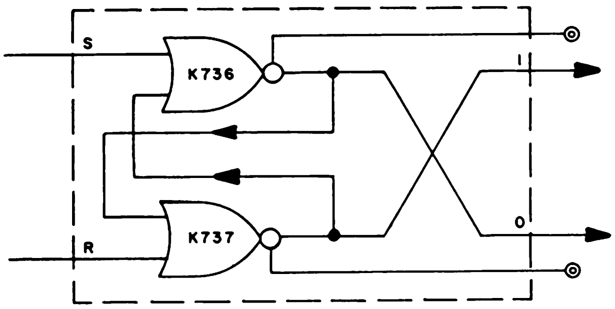

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Figure 6-9.—Flip-Flop Circuit.

to the inputs of each other. The result is the combined circuit functions as a bistable multivibrator. When a FF is placed in one state, it remains in this state until the input to the other state occurs. This characteristic permits it to act as a storage device.

The inputs and outputs to a FF are labeled set or reset. A "1" at the set input sets the FF. The set output is a "1" and the reset output is "0". After the "1" input ceases the output of the circuit remains the same. When a "1" occurs at the reset input, the FF resets. The reset output is now a "1" and the set output is "0". The circuit remains in the reset state until there is a "1" at the set input.

Conventionally, the set output of a FF determines its contents. Thus a FF contains a "1" if it is set and a "0" if it is reset. The outputs of a FF are crossed internally so that the set and the reset outputs leave the same half of the symbol as their respective inputs.

Counter Register

A group of FFs can be interconnected to form a counter. Successive input pulses are recorded by this network. A single rank of FFs record these inputs as a binary code. Two ranks of FFs can also be used to form a binary counter.

A single-ranked counter (fig. 6-10) is advanced by changing the state of only one FF. A set pulse, which bypasses the AND gates, sets the counter to binary 001, FF 0-1 is set while FF 2-3 and FF 4-5 are reset. Since only one gating condition exists at any one time, only one FF is affected by the advance pulse. For example, after the counter is set to 001, the reset output of FF 4-5 and the set output of FF 0-1 enable the advance pulse to set

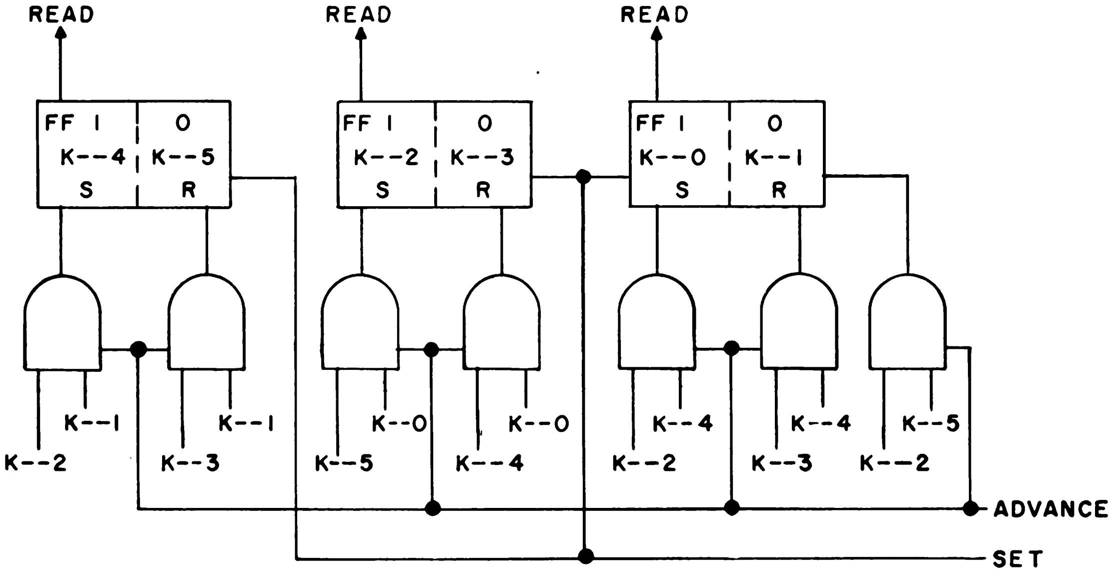

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Figure 6-10.—Single Ranked Counter.

FF 2-3. When the next advance pulse occurs, the set output of FF 2-3 and the reset output of FF 4-5 enables the resetting of FF 0-1. Each successive advance pulse advances the count in the same manner. As each advance pulse occurs, the binary count advances in the following order: 001, 011, 010, 110, 111, 101, 100, 000. These binary coded octal numbers are equal to 1, 3, 2, 6, 7, 5, 4, 0.

A double-ranked counter (fig. 6-11) is a straight binary counter. Following each advance pulse, a transfer pulse occurs which transfers the count of rank one into rank two. The FFs in rank two provide the necessary gating conditions to set or reset the FFs in rank one to advance the count by one for each successive advance pulse.

Assume all the FFs are reset. The reset output of FF 2-3 enables the first advance pulse to set FF 0-1. Since FF 2-3 is reset, none of the AND gates to the second or third FF in rank one are satisfied. Thus the first advance pulse sets the counter to binary 001. The first transfer pulse duplicates this count in rank two.

When the second advance pulse occurs, the set output of FF 2-3 gates this pulse into the reset side of FF 0-1. Because FF 6-7 is reset at this time, the AND gate input to the set side of FF 4-5 is satisfied and neither AND gate inputs to FF 8-9 is satisfied. Therefore, the second advance pulse increases the count to binary 010. The second transfer pulse places this count in rank two.

Since FF 2-3 is reset, the third advance pulse affects only the set input to FF 0-1, and the count increases to binary 011. The third transfer pulse places this count in rank two.

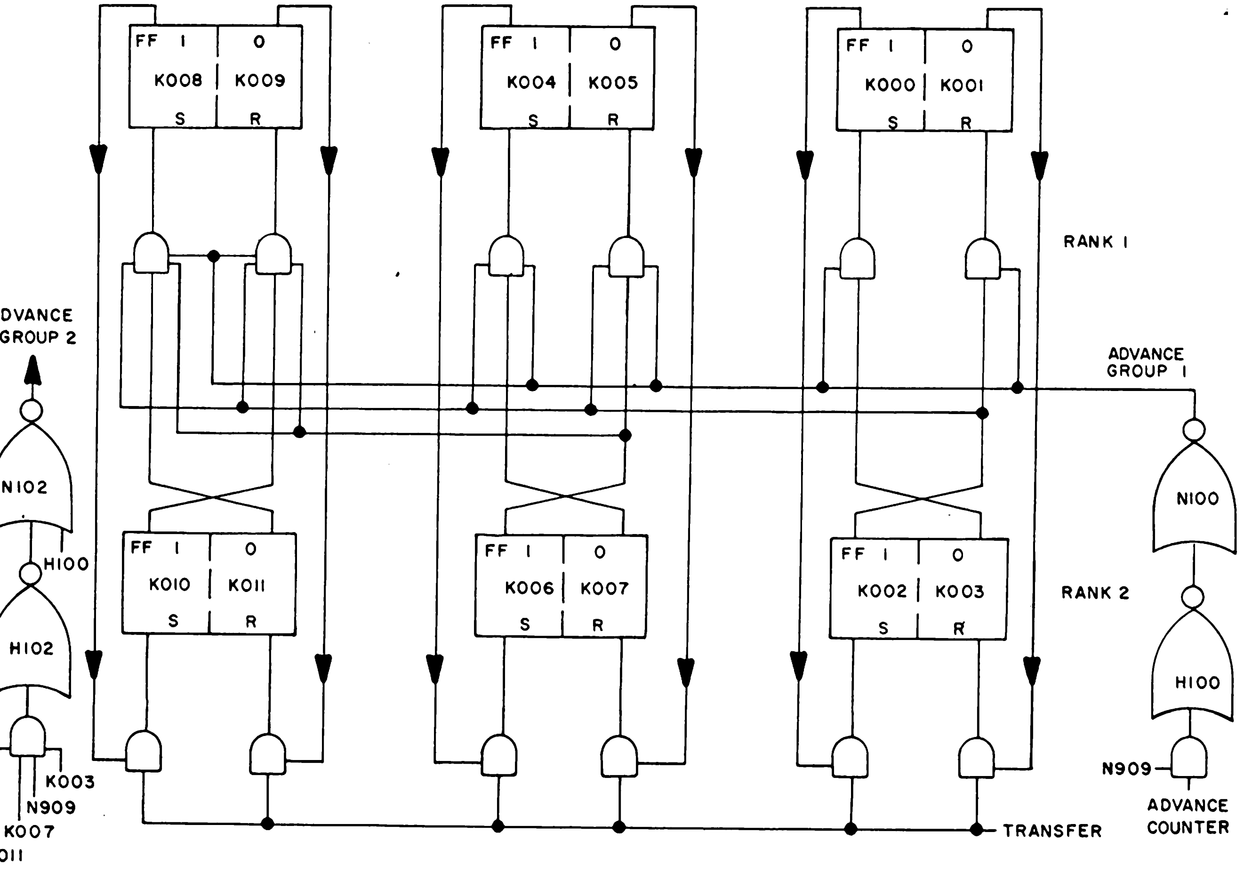

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Figure 6-11.—Double Ranked Counter.

Since FF 2-3 and FF 6-7 are both set, the fourth advance pulse affects all three stages of rank one and the count increases to binary 100. The fourth transfer pulse places this count into rank two. Each successive advance pulse increases the count by one and each successive transfer pulse places the count into rank two. The eighth advance and transfer pulses reset all the FFs and generates a zero output. Thus a three-stage counter permits a count of zero through seven. If the zero output from the counter is the input to a NOR circuit, the resultant "1" output from this circuit could be used as the advance pulse for the next FF or group of FFs. Each time the NOR circuit receives a logic 1 it will generate an advance pulse for the next FF. Three additional stages of FFs would increase the maximum count to 77 in binary coded octal.

### NOR Modules

There are several types of NOR modules which differ only in the number of NOR circuits they contain and hence in the number of inputs and outputs.

A NOR circuit operates as an OR gate followed by an inverter. In some modules one of the inputs to a NOR circuit is diodeless, which means the OR gate is not present in the input circuit to the inverter. This is desirable where more than three variables must be considered by the NOR circuit. The additional variables are applied to an OR gate in other modules and then applied to the diodeless input to the NOR circuit.

### Diode Network Module

The diode network module contains conventional diode circuits. Some of these diodes are arranged as OR circuits and provide additional inputs to the diodeless NOR gate input circuit or isolated OR inputs to transmission gates. These circuits provide three-input OR gates and two-input OR gates. The remaining diodes in the module provide conventional diode circuits for other modules. Like all conventional diodes, when forward-biased they will conduct and complete the circuit through the module, and when back-biased they will not conduct and effectively open the circuit in the module.

### Inverter Modules

An inverter module contains several separate but identical inverter circuits. An inverter circuit inverts and amplifies logic signals that are used as inputs to other modules.

### Flip-Flop Modules

The flip-flop module is used to temporarily store digital information. The flip-flop (FF) has six inputs: set, set trigger, reset, reset trigger, set clear, and reset clear. The set and reset inputs are supplied with digital data or control signals from logic circuits. The set and reset trigger inputs usually receive clock pulses from different pulse generators. When a logic 1 is present at the set input in coincidence with a clock pulse at the set trigger input, the FF sets. When a logic 1 is present at the reset input in coincidence with the clock pulse at the reset trigger input, the FF resets.

The set clear and reset clear inputs provide means of asynchronously clearing the FF and driving it to a desired state. The clear operation is asynchronous because it can occur at any time and is not dependent upon coincidence with the trigger inputs. If a FF that is set, receives a logic 1 on its reset clear input, the FF automatically resets. A logic 1 applied to the set clear input of a reset FF causes it to set.

In addition to the FF circuit, the module contains diode circuits. These diodes are arranged to provide "OR" input and output gating circuits.

### Register Flip-Flop Modules

A register flip-flop module contains two identical FF circuits and is used with other modules of this type to multistage FF registers. The module has four inputs: set, reset, trigger, and reset clear. Inputs on the set and reset lines are digital data or control signals from logic circuits. The trigger input receives clock pulses from a pulse generator. A logic 1 on the set input in coincidence with a clock pulse at the trigger input causes the register FF to set. Coincidence of a logic 1 on the reset input with a clock pulse on the trigger input resets the register FF. An asynchronous logic 1 applied to the reset clear input allows an override reset of the circuit.

### Relay Modules

A relay module contains a group of double-pole, double-throw relays. Primarily, these relays are used for circuit protection and control. However, due to their bistable operation, relays can be used in logic circuits. A d-c signal energizes the relay winding. The circuitry associated with the relay can be designed so the open condition of the relay contacts equals a logic 1 and the closed condition a logic 0 or vice versa.

### Shift Register

A quantity stored in a double-ranked register can be shifted to the right or to the left. Shifts are made one stage at a time and may be made up to the register width. The instruction word that orders the shift also contains the number of places the stored quantity is to be shifted. In some cases two registers are tied together and effectively double the register width. For example, two 24-bit double-ranked registers working in conjunction with one another form a 48-bit register. In these cases a shift operation is accomplished as if there is one register. Shifts are made from the upper or first rank of the register to the next stage in the lower or second rank, the direction, right or left, depends on the type shift. A subsequent command places the shifted word into the upper rank.

Generally, right shifts are end-off, as a word is shifted to the right the least-significant bit is lost. Since we are shifting toward the least-significant bit this is equal to dividing the word in the register by binary 10. The sign-bit is maintained in the most-significant stage and is effectively shifted to the left for as many stages as the word is shifted.

For right shifting the circuits associated with the register include an AND gate in the set side of each stage except the highest-order stage. The inputs to these AND gates are from the right-shift control and from the set output of the next higher stage in rank one. When the right-shift command occurs, the quantity in rank one is shifted one place to the right into rank two. The lowest-order bit, which is stored in the extreme righthand stage, is dropped, (end off). After the shift, the contents of rank two is duplicated in rank one.

For a left shift, the set side of each stage in rank two has an AND gate input. The inputs to these AND gates are from the left-shift control and the set output from the rank one of the next lower stage. However, the lowest stage receives its input from the highest-order stage, (end around). When the left-shift command occurs, the word in rank one left shifts one place into rank two. Since we are shifting toward the most-significant bit, a left shift is equal to multiplying the word in the register by binary 10. The sign bit of the stored word appears in the least significant stage after each shift and all other positions move one place to the left. After the shift the quantity in rank two is duplicated in rank one.

The shift operation can be ordered directly by an instruction word and is fundamental to the arithmetic operations of the computer. During arithmetic operations, a stored quantity that is an operand in a multiplication or division problem must be shifted to maintain its relative magnitude. We will discuss the computer arithmetic methods next.

## ARITHMETIC SECTION

All information in the computer is represented and manipulated in the binary number system. The binary information is represented by different voltage levels. There are four basic arithmetic operations: addition, subtraction, multiplication, and division. We will base our discussion of the arithmetic operations on a digital computer that utilizes a series of registers to perform the calculations. It should be noted that the arithmetic operations may be performed using many different methods. A complete coverage of these methods is contained in Digital Computer Basics, NavEdTra 10088-A.

### ARITHMETIC REGISTERS

The arithmetic section of the computer has three registers designated A, Q, and X. Associated logic circuits permit utilizing the registers in arithmetic operations and the manipulation of the words in the registers. These registers are made up of register FF modules which were described earlier in this chapter.

### A Register

The A register is called the accumulator register because the results of arithmetic problems are usually accumulated in this register. The A register can operate separately or in conjunction with the Q register. It can communicate with the Q and the X registers.

Associated with the A register is the borrow pyramid, a network for sensing and generating the borrows required in subtraction. Two of the more important functions of the A register are:

1. holds one of the operands of an arithmetic problem and usually accumulates the results of the problem, and
2. shifts the word it contains to the right or left; the shift may be accomplished separately or in conjunction with the Q register.

### Q Register

The Q register is the auxiliary arithmetic register. It communicates directly with the A register only. The principal functions of the Q register are:

1. provides temporary storage of the contents of the A register
2. forms a double-length register with the A register—AQ or QA
3. shifts its content to the right or left, separately or in conjunction with the A register
4. participates in arithmetic operations.

### X Register

The X or exchange register is the communication center of the computer. All internal transmissions between the arithmetic section or the input-output section and the rest of the computer are made through the X register. The principal functions of the X register are:

1. communication between sections of the computer,
2. participation in arithmetic operations,
3. complementation of its contents, and
4. formation of logic products.

### Associated Control Section Registers

Two registers of the control section designated U and R are also used in arithmetic operations. The U register is the program control register of the computer. In addition to its storage function, the U register is a subtractive accumulator that can perform arithmetic operations. The R register has provisions for counting and complementing as well as storage. As a counter it operates subtractively. In shifting operations, the R register acts as the shift counter.

## BINARY ARITHMETIC

We will consider a digital computer which uses only positive numbers in its arithmetic operations. The sign bit of an operand is sensed and stored as the first step in the arithmetic process. A zero sign bit indicates a positive number and a one sign bit indicates a negative number. If a negative number is sensed it is complemented to provide a positive number. After the arithmetic operation is completed, logic circuits assign the proper sign to the result as determined by algebraic rules.

Arithmetic is performed in the computer by the ones complement method. The circuits that perform the arithmetic are subtractive; thus, addition as well as subtraction is accomplished subtractively. Multiplication and division problems are solved by the over-and-over addition and subtraction methods respectively. Multiplication and division are repetitions of a two-part step which consist of: (1) an addition (for multiplication) or subtraction (for division); and (2) shifting.

We will state the four conditions that are possible and the rules for binary addition and subtraction before we discuss ones complement arithmetic. The rules for binary addition are:

| Augend | | Addend | | Sum |
|---|---|---|---|---|
| 0 | + | 0 | = | 0 |
| 0 | + | 1 | = | 1 |
| 1 | + | 0 | = | 1 |
| 1 | + | 1 | = | 0 with a carry of 1 |

The rules for binary subtraction are:

| Minuend | | Subtrahend | | Difference |
|---|---|---|---|---|
| 1 | - | 0 | = | 1 |
| 1 | - | 1 | = | 0 |
| 0 | - | 0 | = | 0 |
| 0 | - | 1 | = | 1 with a borrow from the next higher-order bit |

### One's Complement Arithmetic

The complement of a number is another number that completes the original number with respect to a known reference. In the decimal number system the ten's complement of the number six is the number four. By arithmetic, subtract each digit in the decimal integer from nine, then add one to the result to obtain the ten's complement. If we do not add one, the result is the nine's complement of the original number. Just like the nine's complement in the decimal system, we have the one's complement in the binary system. The one's complement is obtained by subtracting each bit in the number from one. This is equivalent to substituting a one for each zero, and a zero for each one in the number. The process is also termed "inversion" and toggling."

Subtraction by complements may be performed as an addition. We will use a decimal example for clarity of explanation to illustrate subtraction by complements:

| | |
|---|---|
| 8 minuend | 8 |
| -6 subtrahend | +4 (10's complement) |
| 2 difference | 2 (omit carry) |

The omission of the carry has the effect of reducing the result by ten. This process is proven in the following manner:

$$8 - 6 = 2$$
$$8 + (10 - 6) - 10 = 2$$
$$8 + 4 - 10 = 2$$

Thus subtraction can be performed by "adding the complement."

Addition by the complement method can be performed by subtraction. The following example using decimal numbers shows addition by a subtractive process:

6 + 2 = 8
6 - 8 (10's complement of 2) = -2
10 (reference base) - 2 = 8

Obviously, complemental arithmetic in the decimal number system is awkward. But the complement method lends itself to binary arithmetic which has relatively simple arithmetic rules. Moreover, since addition can be performed subtractively, a computer using one's complement method need perform only one basic arithmetic operation, namely subtraction.

## ADDITION

Perhaps the most important function of the arithmetic section is the basic operation of addition because it is used in most other operations. The following equation is used by the computer to perform addition by subtraction:

$$A + X = A \overset{\text{subtractive accumulator}}{-} (\underset{\text{transmit the 0 output of X}}{-} X)$$

The equation states that the quantity in the X register is added to the quantity in the A register by subtracting the complement X (written as $X'$ or $\overline{X}$) from A. The notes in the equation indicate the manner in which the computer accomplishes addition.

Fundamental to the performance of subtraction is the generation of borrows. If the bit in the subtrahend is larger than the bit in the minuend a borrow from the next higher-order stage of the register must be made in order to obtain a positive answer. In other words, we cannot subtract 1 from 0 and obtain a positive answer without borrowing. When a borrow is required it "backs" a stage of the A register one count. The same principle of borrowing used in pencil and paper subtraction is also used by the register. The borrow feature makes the A register subtractive rather than additive. If the register were additive, it would use the "carry" procedure.

In the addition of X to A the minuend is in the A register and the subtrahend is the complement of the word in X. The result of the operation is governed by two conditions: (1) what must be done to $A_n$ to obtain the difference without borrows of $A_n$ and $\overline{X}_n$; and (2) whether the arithmetic difference of $A_{n-1}$ and $\overline{X}_{n-1}$ requires a borrow be made from $A_n$. The subscript "n" indicates a particular stage in the register. Therefore, "n-1" indicates the stage preceding or to the right of the n stage, while "n+1" indicates the stage following or to the left of the n stage.

FIRST CONDITION.—A determination of the need for a borrow can be made by studying the relationships bit-by-bit between the minuend and the subtrahend. There are four possible relationships in binary subtraction and the difference column indicates the logical or bit-by-bit difference between the associated minuend and subtrahend, (rules for binary subtraction.) The logical difference does not consider the arithmetic difference, it is determined solely by the relationships involved. In making this determination the one's complement of the word in X is used.

If the subtrahend is zero, the difference has the same value as the minuend. We are subtracting zero from the associated bit in the A register. Therefore, when the complement of the bit in the X register (subtrahend) is zero, the associated stage in the A register contains the logical difference of the bits in these stages.

Conversely, if the subtrahend is one, the logical difference is the reverse of the minuend. Where the minuend is zero and the subtrahend is one a borrow from the next higher-order stage is required. Here we are subtracting one from the associated stage in the A register. Therefore, the logical difference of the minuend in A and the subtrahend $\overline{X}$ is formed by toggling (individually complementing) each bit of A for which the corresponding bit of $\overline{X}$ is a one. After toggling the required stages in A, it contains the logical difference between A and $\overline{X}$.

SECOND CONDITION.—The second condition in the addition of A to X indicates what borrows must be made to form both the logical and the arithmetic differences. It is necessary to borrow from stage $A_n$ when both $A_{n-1}$ and $X_{n-1}$ were initially zero; in other words, a borrow from $A_n$ means that the logical difference of $A_{n-1}$ and $X_{n-1}$ is zero. This follows, since the complement of X is subtracted from A. When $X_{n-1}$ is a zero, its complement is one, and it is the complement of $X_{n-1}$ which is subtracted from $A_{n-1}$.

COMBINING THE TWO CONDITIONS.—The addition of X to A is accomplished by toggling A as determined by the logical and arithmetic differences. For each stage of A the two conditions for toggling are combined to gate the command, "add X to A." If this AND gate is satisfied, then $A_n$ is toggled. Following the occurrence of the toggle command, A holds the sum of X and A.

Since the two conditions are independent, it is possible for both to be satisfied at the same time for a given stage. If both conditions require $A_n$ to be toggled, then $A_n$ is not toggled, since complementing a stage twice restores it to the initial state. Also, if neither condition is satisfied, $A_n$ is not toggled. Only if one of the conditions (but not both) exist is $A_n$ toggled. An exclusive OR gate is used to gate the Add command. Thus, $A_n$ is toggled when: (1) $X_n$ is zero and no borrow is required from $A_n$; (2) $X_n$ is one and a borrow is required from $A_n$.

If a borrow is required from $A_n$ and it is a zero, then a borrow will be required from $A_{n+1}$. If $A_{n+1}$ is zero, then a borrow will be required from $A_{n+2}$, and so on. If a borrow is generated in the highest-order stage, it is made from the lowest-order stage. This is an end-around borrow which makes the A register a one's complement arithmetic device.

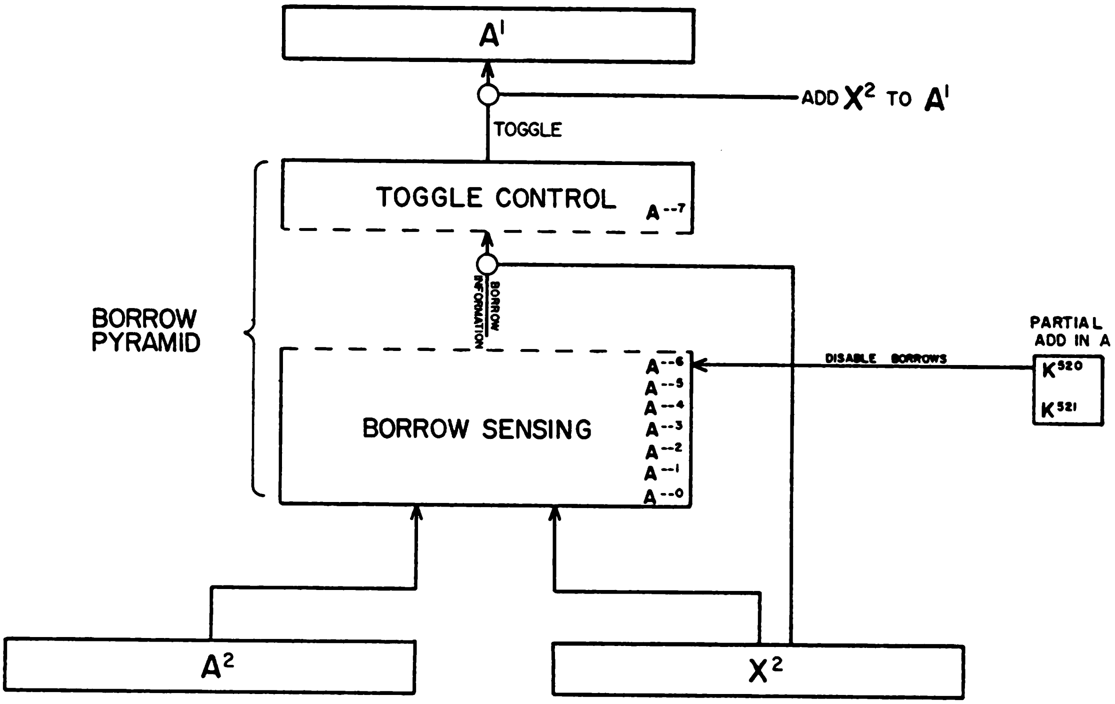
The following example shows the addition procedure. The logical difference of A and X initial (Ai and Xi) is formed by complementing each bit of Ai where the corresponding bit of Xi is zero. The other bits of the logical difference are the same as those in Ai. Generation of borrows is made with the aid of the logical difference. A borrow is generated in any stage where A and X are both zero. The borrow is represented by an arrow which points to the stage from which the borrow is made. If the borrow points to a stage that has a logical difference of zero, another borrow is required. The T's indicate the stages of A that are toggled by the command add X to A. Note that a T exists in the stages where $X_n$ is zero and no arrow points, or $X_n$ is one and an arrow points to it.

| | | |
|---|---|---|
| Augend in A | 0 1 0 1 | +5 |
| Addend in X | 0 0 1 1 | +3 |
| Logical difference | └1 0 0 1↰ | |
| Stages to be toggled | T T   T | +8 |
| Sum of A and X (obtained by toggling A in each stage with a T) | 1 0 0 0 | |

Borrow Pyramid

The purpose of the borrow pyramid is to sense each stage of A and determine whether one or the other of the two conditions exist that require $A_n$ be toggled in the addition of X to A.

The borrow pyramid (fig. 6-12), senses the stages of A from which borrows are required and sends signals to them. These signals accomplish borrows by toggling the necessary stages. The pyramid is a network of inverters (NOR gates), part of which senses borrows (the $A^0$ through $A^6$ inverters) and part of which senses where A must be toggled ($A^7$ inverters,



177.33

Figure 6-12.—Relation of Borrow Pyramid to A and X Registers.

only one is shown.) The borrow sensing is accomplished by sampling $A^2$ and $X^2$. The result of borrow sensing is combined with $X^2$ as the input to the toggle control. The toggle control determines what stages of $A^1$ are to be toggled by the add $X^2$ to $A^1$ command.

The borrowing sensing section is disabled when the "Partial add in A" flip-flop is cleared. This permits the add command to simply toggle $X^2$ into $A^1$. Since this amounts to an add without carries, it is called a partial add.

## SUBTRACTION

In a subtraction problem, the minuend is in the A register and the subtrahend in the X register. Subtraction is accomplished in three steps: (1) complement X; (2) sense borrows by means of the logical difference of A and X; and (3) form the arithmetic difference by toggling as indicated by the borrow situation. The first step is accomplished by complementing $X^1$ into $X^2$ ($X^1 \rightarrow X^2$). Therefore, it is the complement of the subtrahend which is subtracted from the minuend in A. Since this means X is in effect complemented twice during the operation it follows that the procedure reduces to A - X. The remainder of the subtraction procedure is the same as that used in addition.

## MULTIPLICATION

Multiplication in the computer is performed by repeated addition and shifts. The multiplication instruction causes the computer to form the product of two operands; the multiplier is contained in register A and the multiplicand, which is taken from storage, is placed in the X register. The product is accumulated in the A and Q registers working in conjunction with each other. The multiplier stored in A is transferred to Q and then sequentially inspected beginning with the least-significant bit. The magnitude of each bit determines whether or not the multiplicand is added to the current partial product. If the multiplier bit being inspected is a one, the multiplicand is added to the partial product. Prior to the next addition, the partial product is shifted to maintain the placement magnitude of the partial product with respect to the order of the current bit in the multiplier. If the bit being inspected is a zero, no addition is necessary and the partial product is shifted to maintain its relative magnitude. After the shift, the multiplication step dealing with this bit in the multiplier is completed. When all the bits in the multiplier have been inspected, the partial product is the product of the two operands and is contained in the A and Q registers.

Let's examine this method of multiplication in more detail. Binary multiplication is performed on a bit-by-bit basis. Since the product of any two bits is always a single bit, there are no carries. The rules for binary multiplication are:

| Multiplicand | | Multiplier | | Product |
|---|---|---|---|---|
| 0 | X | 0 | = | 0 |
| 0 | X | 1 | = | 0 |
| 1 | X | 0 | = | 0 |
| 1 | X | 1 | = | 1 |

Note that if either of the operands is zero, the product is zero.

Consider the following problem:

| Decimal | | Binary |
|---|---|---|
| 14 | | 1110 |
| x 12 | | x 1100 |
| 28 | | 0000 |
| 14 | Partial | 0000 |
| 168 | Products | 1110 |
| | | 1110 |
| | | 10101000 |

The partial products are shifted to the left to place the digits in the proper columns. Thus, the true value of the partial product 14 is 140 because it was the result of multiplying the 10 part of the 12 times 14.

To avoid adding more than two numbers simultaneously, the computer keeps a running subtotal of the partial products. Rather than shifting the partial products to the left to position it correctly as is done in pencil and paper multiplication, the computer accomplishes the same function by shifting the subtotal of the partial products one place to the right before the next addition is made. This means that in the next addition, the augend has been shifted one place to the right which has the effect of shifting the addend one place to the left with the result that the sum, which is the partial product in the multiplication problem, is in effect multiplied by binary 10. The partial product is not shifted after the final addition of the sequence.

The advantage of right shifting in multiplication is economy in computer design. At the start of the multiplication sequence, the multiplier is transferred from the A register to the Q register. The lowest-order stage of the Q register contains the least-significant bit of the multiplier. Since a right shift is an end-off shift, after the least-significant bit is inspected, it is discarded by the shift. This positions the current multiplier bit in the lowest-order stage of the Q register and the upper stages of the register become available to receive the least-significant bits of the partial product as it is accumulated. The A register right shifts these bits into the Q register. Thus, the A and Q registers can accommodate both the multiplier and the product simultaneously.

As the multiplication problem evolves, the contents of the X, Q, and A registers would appear as follows: (For brevity, the registers are considered as containing four bits).

X Register

1110

| | A | Q | |
|---|---|---|---|
| Initial | 1100 | 0000 | |
| Step 1 | 0000 | 1100 | Interchange A and Q |
| Step 2 | 0000 | 0110 | Add 0 (least significant digit of multiplier) times X to A, shift right one. |
| Step 3 | 0000 | 0011 | Add 0 (second digit of multiplier) times X to A, shift right one. |
| Step 4 | 0111 | 0001 | Add 1 (third digit of multiplier) times X to A, shift right one. |
| Step 5 | 1010 | 1000 | Add 1 (last digit of multiplier) times X to A, end of multiplication sequence. Product contained in both A and Q registers. |

The multiplication sequence in the computer may be divided into three parts:

1. initial sign correction,
2. multiplication phase, and
3. final sign correction.

During initial sign correction the multiplier and the multiplicand are made positive, if they were not so originally. If the signs of the two were unlike, a sign record flip-flop is set, (product is negative). If the signs are alike the flip-flop is cleared, (product is positive). Following the initial sign correction, the multiplication sequence generates a control quantity which determines the number of steps needed to conclude the multiplication phase. This number is transmitted to the R register in the control section of the computer. As each step is completed, the number in the R register is reduced by one. When R equals zero, the multiplying steps have been repeated the number of times specified by the control quantity and the product accumulation is terminated.

The product is a positive number, with a zero sign bit. If the operands were initially of opposite signs the product should be negative in accordance with algebraic rules. In which case the product in registers A and Q is complemented. The signal to complement the product is generated by the sign record flip-flop which is set.

DIVISION

The divide instructions in the computer call for the division of a word in the A and Q registers by a divisor which is in storage at an address specified by the instruction. The divisor is transferred from storage to the X register. Division is performed in three phases: initial sign correction, division phase, and final sign correction. The initial sign correction phase is similar to the same phase of the multiplication sequence. The signs of the operands are sensed and made positive, and a control quantity is set in the R register. The dividend is positioned in the A and Q registers with the higher-order bits in A.

The divide steps in the computer are:

1. left shift AQ one place
2. subtract X (divisor) from A (partial dividend) if A is equal to or greater than X (A≥X)
3. set Q least-significant digit to 1 if a subtraction was made; otherwise set to 0

The following example shows the pencil and paper method and the computer method of division.

| Binary | | Decimal |
|---|---|---|
| 1110 | Quotient | 14 |
| Divisor 1101⟌10111001 | Dividend | 13⟌185 |
| 1101 | | 13 |
| 10100 | Partial | 55 |
| 1101 | Dividends | 52 |
| 1110 | | 3 |
| 1101 | | |
| 00011 | Remainder | |

X Register (Divisor)

01101

| A Register (Dividend) | Q Register (Quotient) | |
|---|---|---|
| 00101 | 11001 | |
| | | Shift AQ left |
| 01011 | 10010 | |
| | | A<X Shift AQ left |
| 10111 | 00100 | Set Q LSD to 0 |
| | | A>X Subtract X from A |
| 01010 | 00101 | Set Q LSD to 1 |
| 10100 | 01010 | Shift AQ left |
| | | A>X Subtract X from A |
| 00111 | 01011 | Set Q LSD to 1 |
| 01110 | 10110 | Shift AQ left |
| | | A>X Subtract X from A |
| 00001 | 10111 | Set Q LSD to 1 |
| 00011 | 01110 | Shift AQ left |
| Remainder | Quotient | |

A left shift is an end-around carry. Note that instead of shifting the divisor right to position it for subtraction from the partial dividend as is done in pencil and paper division, the computer shifts the partial dividend left. This accomplishes the same purpose and is equivalent to dividing the partial dividend by binary 10. Thus, all the arithmetic operations can be performed in the A register and the quotient can be accumulated in the Q register. The direction of the shift is different but the principle involved is the same as described in multiplication.

The final sign correction consists of:

1. sense for a divide fault
2. complement Q (the quotient) if the sign record flip-flop is set (dividend and divisor initially have unlike signs)
3. complement A (the remainder) if dividend sign flip-flop is set (dividend negative initially)

In a division problem the relationship of the size of the dividend and the divisor must be considered in order to express the quotient within the capacity of the Q register. A divide fault (Q register overflow) results when the correct quotient cannot be contained in the Q register. If a division involves a fault, then after the first shift of the division phase, A will be greater than X ($A>X$) and a one is entered in the Q register least-significant digit (see example of division problem). But if a division fault is not involved, then after the first shift $A<X$ and a zero is entered in the Q register LSD. In either case, this bit appears in the highest-order stage of the Q register after the remaining shifts of the division phase. Thus, if Q is negative, (the sign bit is one), there is a fault, if Q is positive (the sign bit is zero), there is not a fault. A divide fault flip-flop is set if Q is negative.

The remaining functions of the final sign correction phase are self explanatory.

## MEMORY SECTION

A computer's arithmetic section is fast. Its calculating speed is measured in nanoseconds (billionths of a second), thus indicating it must be fed data at a fast rate.

To quickly find data to work on, it is stored in memory and assigned a specific address. Knowing where the data is, it can be found and taken out in microseconds. In this section we will discuss some of the terminology which is peculiar to memory, the methods of magnetizing the memory unit and some of the magnetic devices used to store and to hold data and instructions.

### MEMORY TERMINOLOGY

In discussing the operation of the memory section, certain terminology is used which is peculiar to memory. We will briefly define these terms in the following paragraphs.

Internal storage refers to storage which the programmer, or coder, would normally use. It is located within the arithmetic unit or main storage, and is characterized by high speed and low capacity.

Secondary storage is cheaper and slower in access, but it has larger capacity. Access time could be as short as milliseconds for magnetic drums or as long as minutes for magnetic tapes. Blocks of secondary storage are normally transferred to the arithmetic unit as required, instead of addressing a specific storage location of a specific stored word.

External storage refers to punched cards, punched tapes and magnetic tapes stored in files or cabinets, which the computer does not have direct access to. External stored information is in a form which the computer can use, but it is physically separate from it.

The capacity of a storage device is measured by the amount of information in bits it can store. The storage capacity of a flip-flop is one bit. A register can store one word at a time, but an array or matrix of magnetic cores may store 10,000 words with fairly small bulk (each core may have an outside diameter of only 50 mils). The storage capacity of magnetic tapes used for external (slow access) storage may be essentially without limit.

Access time refers to the time required to write in and read out information from storage, including the time to communicate with the storage location. If destructive readout is employed, the "destroyed" information must be written back in before the cycle is complete. Random access is said to occur if access to any storage location is independent of the storage address of the previous word. Access is said to be cyclic if the access time depends on the location of the previous word, as in the case of a rotating magnetic drum. (With a rotating magnetic drum, the addresses available at any given instant depend on the instantaneous drum position).

Random access time for internal storage may be typically a few microseconds, but for secondary storage, milliseconds to minutes will be required.

Static or dynamic storage refers to whether the information changes location or not (when it is not being used). Examples of static storage devices are flip-flops and magnetic cores. Examples of dynamic memory devices are delay lines (with circulating pulse trains) and rotating magnetic drums.

Erasable storage is widely used in computers since it is essential in many instances to be able to store different words at different times at the same storage location. Examples of erasable storage include magnetic drums and magnetic tapes. Examples of nonerasable storage are punched cards and punched tapes.

Volatility relates to the loss or alteration of stored information due to an unintentional power loss. Regeneration or the periodic reinforcement of stored information, which is a common practice in dynamic storage, usually results in a volatile situation.

Serial (series) access refers to reading or writing one bit at a time. When all bits of a word are transferred simultaneously, operation is said to be parallel. Only the smaller binary computers are entirely serial in storage access; on the other hand, very few computers use parallel storage systems altogether. Most use a series parallel arrangement. A parallel arrangement provides high speed at the cost of a great amount of additional equipment. On the other hand, a completely serial situation is usually too slow.

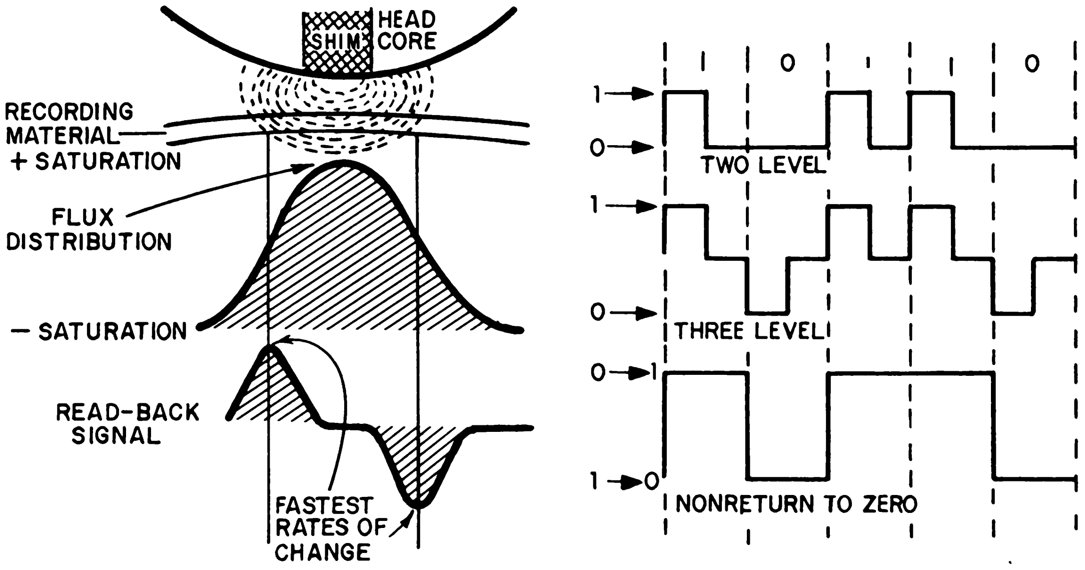
## MAGNETIZING THE MEMORY UNIT

The process of recording a 0 or a 1 on a magnetic medium involves two opposing problems:

1. To obtain the highest packing density (storage of the maximum number of bits in the minimum space).
2. To maintain reliability (ability to recognize and use the stored data).

In order to obtain the highest packing density, considerable distortion must be tolerated. A saturation amplitude signal is normally used to record digital data, and this results in a gross distortion of the input signal. Figure 6-13A illustrates the type of distortion involved.

Signals are produced when the recording material is moved by a pickoff winding in such a manner that cutting of magnetic lines of force takes place. This occurs at the beginning and the end of the magnetized portion of the recording material. No signals are produced by the saturated portion of the recording material because the magnetic lines of force are aligned with the direction of movement. The magnetic



(A)

(B)

167.117

Figure 6-13.—Magnetic Recording. A. Recording Method, Showing Distortion; B. Recording Levels.

airgap (shim) dimensions determine the amount of material needed to record a single data bit.

The amplitude of signals recorded may be two-level or three-level, depending on whether a condition of zero magnetization is allowed to exist other than momentarily. Figure 6-13B is an idealized representation of the binary number 10110 (decimal 22). The top waveshape represents the two-level signal, and the center waveshape represents the three-level signal. In the three-level system, note that zero magnetization exists during the latter half of each data bit, and that the polarity of the magnetization is reversed for the 0 or 1 digits.

In a third system of recording (shown in the bottom waveform of figure 6-12B), no change of output is permitted when succeeding digits are the same; therefore, no playback signal appears at this time. This is called the NON-RETURN-TO-ZERO method of recording. With a long series of 1's, counting the time intervals is done by clock timing pulses. A separate recording track is usually devoted exclusively to recording these synchronizing signals.

Because the readout signal waveform differs greatly from the read-in signal, additional circuitry is frequently used to restore the signal to its original shape. This circuitry normally consists of a saturation amplifier and clippers.

## MAGNETIC STORAGE DEVICES

The choice of the storage medium to be used in a computer is dependent upon several factors. Among these are (1) the intended computer use or purpose, (2) physical size, (3) cost, (4) power consumption of the equipment, (5) access time, and (6) reliability. (Reliability is a measure of the ability of the computer to function without failure over a long period).

The type of storage device determines the size and amount of data the computer can handle and also affects the timing of the control section. The speed of operation of the storage medium determines (to a great extent) overall time required for the computer to execute a given program.

### Magnetic Drums

A magnetic drum is the cheapest form of internal storage for a small computer; the data stored on the drum is erasable but nonvolatile (not lost when the power is turned off).

The magnetic drum is an aluminum cylinder coated with a magnetic material. Heads for writing on or reading from the drum are mounted so that the drum rotates past and close to them, figure 6-14A. The heads magnetize spots along the drum surface when data is fed into the computer, and pick off data as magnetized spots cause a pulse to appear at their outputs. This action is quite similar to that of a tape or wire recorder, except that the portion of the revolving drum that passes under each head can be thought of as a ring or band of magnetic tape.

Figure 6-14B shows how channels appear on the magnetic drum. To place the maximum number of heads over the drum, the heads are staggered as indicated in figure 6-14C. Each pickup head can be considered as a channel of the rotating drum. Each channel can store approximately 80 bits per inch.

Magnetic memory drums vary greatly in capacity and operating speed. Speeds of 3,000 to 17,000 rpm and diameters of 4 to 12 inches are quite common. Access to data stored on the drum depends on the rotational speed and the location of the particular data desired. When the desired bit has just passed the head, the access time is maximum (one revolution). If the desired bit is under the head, access time is nearly zero. Thus for the general case, average access time is one-half revolution. By improved programming methods, this access time may be further reduced. Average access times in practical computers range from 2 to 10 milliseconds.

The drum shown in figure 6-14D includes a quick access band, each track of which comprises several circulating loops of the type shown in figure 6-14E. These loops waste that portion of track (if any) which is not between the two heads which comprise a loop.

Each channel on the drum is identified, and the location (address) of each bit or word is identified. The channel may be thought of as resembling a motion picture film, with block separations to locate a specific word or bit. The address of a specific binary word is identified as to its channel, block, and location within the block. The blocks will, of course, be very small, as compared with the film.

Many bits are recorded in each block of each channel, and since the bits pass under

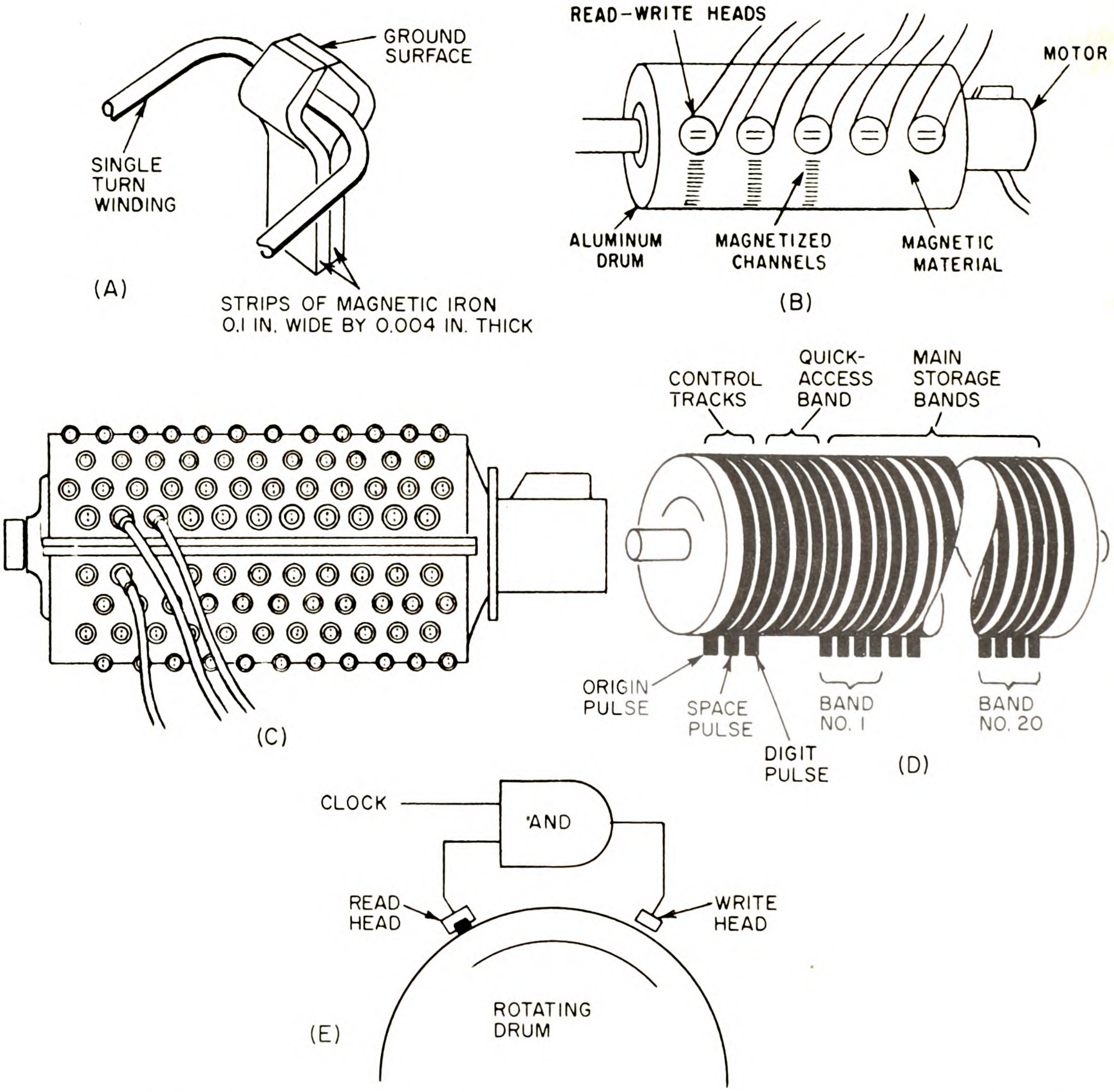


Figure 6-14.—The Magnetic Memory Drum Unit. A. Read-Write Head; B. Magnetic Drum; C. Arrangement of Heads on Drum; D. Arrangement of Tracks on Drum; E. Read-Write Circuit. 167.118

the head one at a time, some method of identifying the start of a word must be provided. The first channels of the drum have magnetized sectors that provide for positive location of a word or digit within a word. These sectors usually contain pulses used for timing, location of words or word groups, word separation, and bits within a word. The timing pulses synchronize the actions of the other channels. In this manner, all the data on all channels is in synchronism with the timing pulse; and if the drum speed varies, every calculation or other operation of the computer varies accordingly. When this feature is incorporated, drum rotational speed is not excessively critical.

A man, known as a computer programmer, determines exactly what operations the computer is to perform and the sequence of those operations. He, then, prepares a program for the computer to follow. Information (data) and instructions (the program) are then placed in the computer so as to provide it with the necessary information and the instructions required to control the flow of information.

The magnetic drum in computers is normally programmed for one specific problem, and is cleared of data after the problem is finished and before the next problem is begun. Each new problem requires that new data be programmed into the drum.

## Magnetic Cores

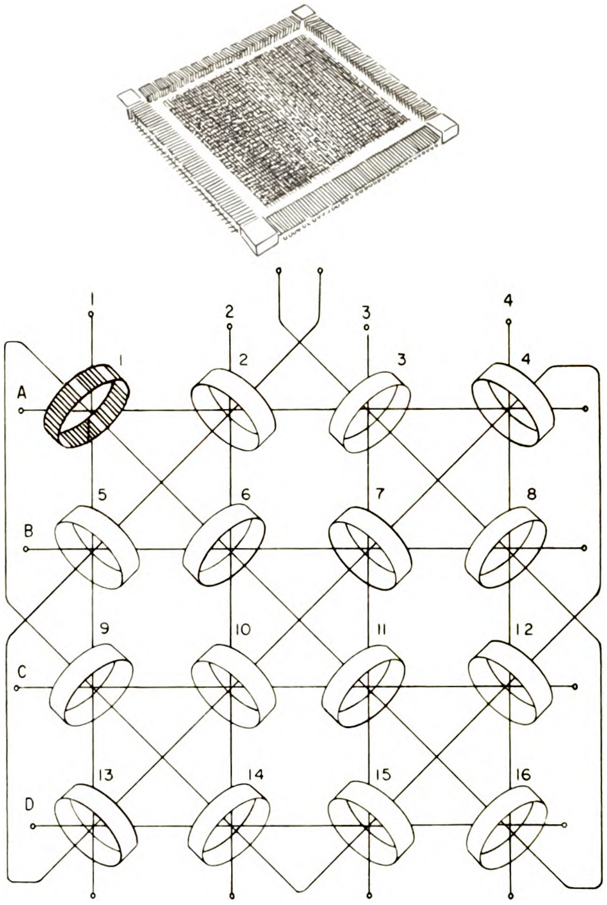
Another type of memory device is the ferrite core. Its principle of operation is similar to that of magnetic amplifiers, in that it is magnetized with a polarity corresponding to the direction of the magnetizing force. The magnetizing force required is modest; a single conductor passing through the core performs the function of a winding.

A magnetizing force applied in one direction magnetizes the ferrite core with a polarity that represents a binary 1, and when applied in the opposite direction causes the opposite polarity which represents a binary 0.

The ferrite core is a small ring of magnetic material, with diameters of approximately 0.05 inch. Figure 6-15 is an enlarged drawing of a section of a ferrite core matrix. A matrix is made up of many ferrite cores connected as shown in the figure, and arranged in a flat panel inside a frame, with wires leading out for easy attachment. Very short access times (10 microseconds or less) are common, because modern high speed semiconductor switches make parallel access practical.

The arithmetc and memory units of a general purpose computer contain many of these matrices. Each core is capable of storing only one bit, so a matrix of 250 cores can store only 250 bits. Multiplying the number of matrices by the number of cores per matrix gives the number of bits that a computer can handle.

In the figure, each core has three windings. The wires that cross at right angles are used to magnetize the core. Using coincident current techniques, any single core may be selectively read in or out. By passing a current through both the horizontal wire and the vertical wire which pass through a given core, the two fluxes may be made to add and to just exceed the threshold value necessary for switching magnetic polarity of the selected core. Each horizontal wire and each vertical wire passes through an entire string of cores. The only core affected, however, is the core at the intersection of the two wires that have the pulses applied. As an example, locate the junction of line B and line 2 on the diagram in figure 6-15. If both line B and line 2 have pulses applied, only core 6 will be affected, because the magnetizing effect of only one wire is not sufficient to cause the magnetization of the other cores to flip to the opposite polarity.



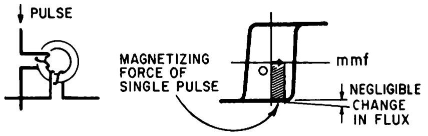
167.119

Figure 6-15.—Ferrite Core Memory Section.

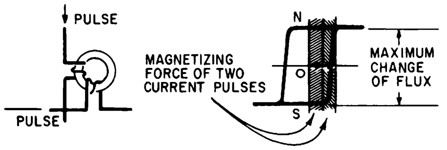
The use of a third (sense) winding (S) permits the sensing of the switching of the core. If interrogated by coincident pulses, the core will switch and the change of flux will induce a pulse into the sense winding. The polarity of this induced pulse is an indication of the binary 1 or 0 that was stored in that core before switching occurred. When the core is read out, the binary bit in that core is lost. This is called destructive readout because the stored data is lost during the read-out process. If it is desired to retain that bit, it is necessary to recirculate and reapply that bit to the core from which it was read out.

Single pulses will frequently be passed through a core when reading into or out of adjacent cores, but these cause no harm. In figure 6-16 the effect of single and coincident pulses is shown. In A, a single pulse is shown to produce a negligible change in flux; in B, coincident pulses are shown to produce a change in flux sufficient to switch magnetic polarity of the core. Residual flux is indicated by the saturation levels, N in one direction and S in the other.

(A) A SINGLE PULSE CANNOT SWITCH THE CORE



(B) COINCIDENT PULSES ON BOTH WINDINGS SWITCH THE CORE



(C) TESTING WAVEFORM

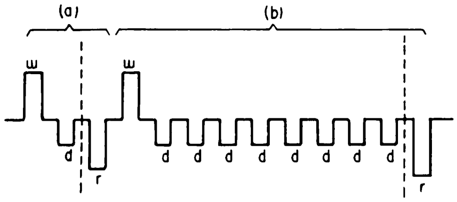


Figure 6-16.—Switching Core Polarity. A. Single Pulse; B. Coincident Pulses; C. Testing Waveform. 167.120

TESTING.—A testing waveform of current may be used to determine the effect of repeated single pulses on a given core. In the ideal situation, a single pulse will have no effect, but this is not necessarily true in practice. To determine the effect of many single pulses on a given core, the waveform shown in figure 6-16C is applied to the core to be tested. A pickup winding is used to sense the response of the core to the testing waveform, and the output of the pickup winding is applied to an oscilloscope which is synchronized with the testing waveform.

The waveform is essentially divided into two parts. Part (a) consists of a write pulse (w), followed by a single disturbing pulse (d) and a read pulse (r). Part (b) is similar, but includes a series of disturbing pulses instead of a single one. The response of the two reading pulses is an indication of the demagnetization of the core caused by several disturbing pulses (b) as compared with the single pulse in (a). If the response to the disturbing pulses is excessive, the core must be rejected.

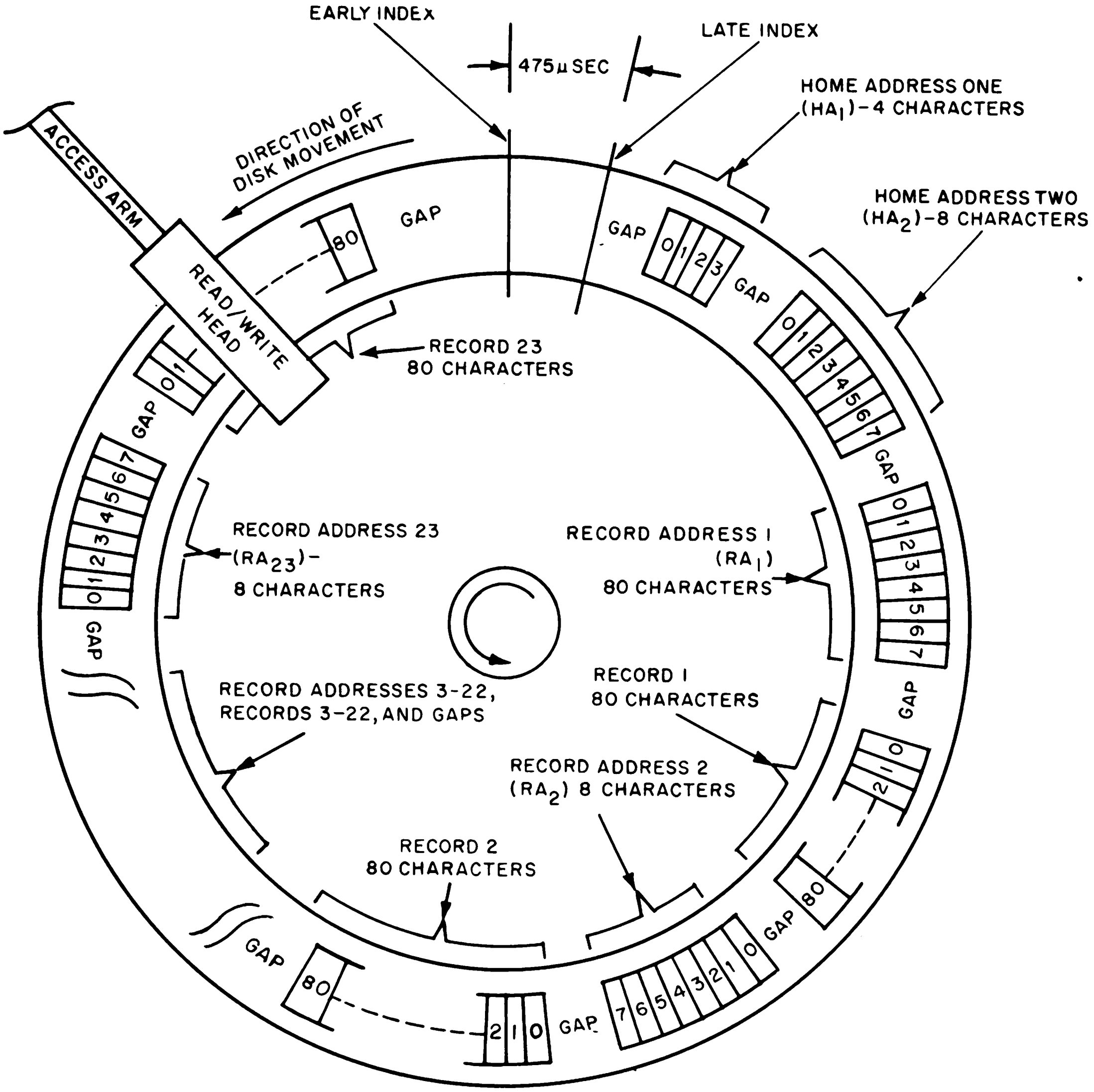
Magnetic Disks

Magnetic disks are a convenient medium for semipermanent storage of mass volumes of production programs. For many applications disks are superior to magnetic tape (discussed later in this chapter) for rapid acquisition and storage of mass volumes of systems programs and data.

Magnetic disks resemble phonograph records which have been coated with iron-oxide. The disks (or records) are arranged in stacks in much the same way as a record stack in a modern "juke box". All of the disks are continuously revolving and spaced apart so that a record head, driven by an access mechanism, can be positioned between the disks.

The data is recorded at certain addresses on a specific disk. When readout of a particular bit of storage is desired, the recording head is automatically positioned and the data is read "serially" from the surface of the selected disk.

The basic unit of information on the disk is a character. By design each character contains a given number of bits (for fixed word applications). One or more of these characters in a group form a record. A circular data track (fig. 6-17), consists of one or more records, associated record addresses, gaps, and data track identification. A track of information as shown in this figure is defined in more detail later. A number of data tracks aligned on vertically arranged disks (fig. 6-18) form a cylinder of information. A magnetic disk file system may contain one or more banks (modules). Each module contains a specified number of



164.43

Figure 6-17.—Circular Data Track.

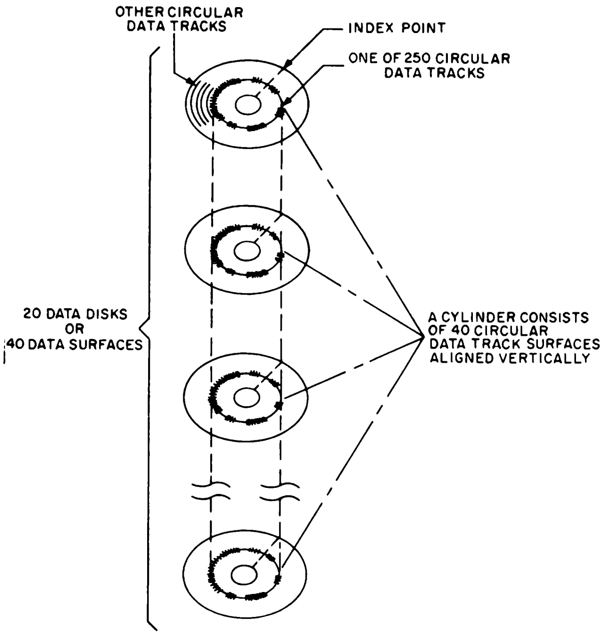
disks with their associated cylinders and data tracks. The flow chart in figure 6-19 illustrates the procedures necessary to retrieve or store information.

TRACK FORMAT.—One basic operating principle must be understood. The data is read or stored serially, character-by-character and bit-by-bit on a data track. All data tracks have the maximum storage capacity.

Index Points.—Each data track (fig. 6-17) must contain a minimum number of control and addressing characters in a specific format. The index points are magnetic marks that indicate the beginning and end of a data track. They are used for timing purposes. In this case, the late index follows the early index by approximately 475 microseconds.

Home Address One.—Home address one ($HA_1$) is a prerecorded number. It is represented in the illustration shown as having four digits. This is the actual address of a data track, and is therefore referred to as the track number. $HA_1$ is the first group of characters to follow the late index.

Home Address Two.—Home address two ($HA_2$) is written by the programmer and serves as a programmer's aid. It can be used for


OTHER CIRCULAR DATA TRACKS
INDEX POINT
ONE OF 250 CIRCULAR DATA TRACKS
20 DATA DISKS OR 40 DATA SURFACES
A CYLINDER CONSISTS OF 40 CIRCULAR DATA TRACK SURFACES ALIGNED VERTICALLY

164.44

Figure 6-18.—Description of Data Storage and Disk Assembly.

category and file numbers as identifiers. It can also be used as a file protect code. For example, it could be used to signal to a second user that this track is normally not to be used.

Record Address.—The record address is also a programmer's aid. It can be used to identify individual records or for any other convenient purpose.

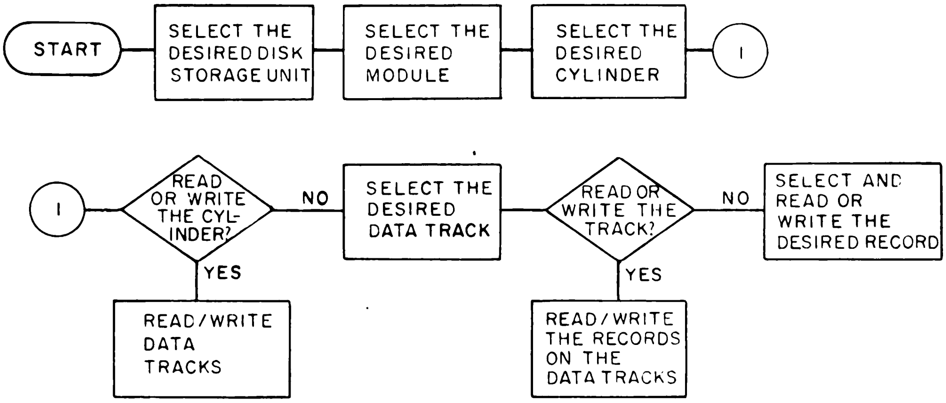
Gaps.—Gaps are written between all address and record areas on a data track. They are used to distinguish specific data areas. Gaps usually contain check characters and internal synchronization information required for proper disk system operation.

Generally, one disk surface in a given module is used only for format tracks. A format track affects the data tracks of the entire cylinder that is vertically in line with it. The format track determines the manner in which data will be read from or written on each track of its associated cylinder. The programmer can write or modify the format tracks as desired.

Track capacity is directly related to the configuration of the format tracks. To record the maximum number of characters on a data track, the data must include Home Address two ($HA_2$), Record Addresses (RA), and Gaps.

SYSTEM COMPONENTS.—A minimum disk file system consists of a disk file controller (DFC), a file control unit, and a disk storage unit. The disk file controller controls the operation of the file control and disk storage units. Specifically, it provides the following functions necessary for the operation of the disk system:

1. data assembly and disassembly
2. signal level conversion
3. function translation
4. parity check
5. parity generation
6. sense and status response


START
SELECT THE DESIRED DISK STORAGE UNIT
SELECT THE DESIRED MODULE
SELECT THE DESIRED CYLINDER
I
I
READ OR WRITE THE CYLINDER?
NO
YES
READ/WRITE DATA TRACKS
SELECT THE DESIRED DATA TRACK
READ OR WRITE THE TRACK?
NO
YES
READ/WRITE THE RECORDS ON THE DATA TRACKS
SELECT AND READ OR WRITE THE DESIRED RECORD

164.45

Figure 6-19.—Flow Chart Illustrating Storage and Retrieval of Data from Disks.

The file control unit accepts instructions from the disk file controller, decodes them, and transmits the appropriate signals to the disk storage unit. In addition, the file control unit provides control timing, read, write, and sense timing, parity and character generation, parity and character checking, format circuits, and data comparison circuitry.

The disk storage unit contains magnetic disk modules. The disks in each module are mounted on a common shaft and rotate at a given speed.

### Magnetic Tape

Perhaps the most familiar type of storage is magnetic tape. The materials used for recording may be the same as those used for audio recording, except that a very high quality tape is required to avoid missing an occasional bit. Seven-channel tape (common in computer work) is usually one-half inch wide, and has a recording density of 100 to over 500 bits per inch. A 2,400 foot roll can store about 3 to 16 million characters. (This is less than the apparent maximum, because the gap between recorded sections of tape may be from 1/2 to 2 1/2 inches). Obviously, the tape must be brought up to operating speed before reading or writing is begun. Actual tape speed may be as high as 240 inches per second.

Since input and output devices are generally mechanical, it may be advantageous (both for speed and economy) to record the computer output at its optimum speed on tape, and later play it back at any convenient speed into the appropriate terminal unit. Similarly, a separate tape track may carry other data essential to the evaluation of the tape.

Tapes produced by computers are used extensively for controlling other processes. Since the data is digital, it can be operated at various speeds, and even stopped, with no loss or distortion of data while other operations are performed.

Many techniques are available to overcome random data acquisition on tapes. These include use of multiple tracks, multiple read heads, etc. The chief advantage of magnetic tape is its ability to store millions of data bits inexpensively. Under ordinary operating conditions, magnetic tape is usable up to 50,000 times. Data on a used tape may be transferred to a new one. Temperature and humidity must be controlled, as variations may cause the oxide surfaces to crack. Since dust may cause a signal to be missed, extreme care in manual handling is necessary. Oil or moisture from manual handling may encourage the collection of dust.

## INPUT/OUTPUT SECTION

The input/output section provides the computer with the facilities necessary for communicating with external equipment. Input devices such as consoles, card readers, and typewriters supply the computer with data and instructions, while output devices provide the means for changing the data processed by the computer into a usable form. The selection of input/output devices depend on the specific use for which a computer is intended.

Different types of computers are used for different purposes. The three major areas of application are business, the solution of scientific problems, and the automatic control of weapons systems. The types of input/output devices used with each application will differ in many respects. In fact, some input/output devices are designed specifically for use with one of these applications and therefore will not be useful with other applications.

## GENERAL REQUIREMENTS FOR INPUT/OUTPUT DEVICES

Generally, input/output devices must meet two basic requirements. First, the devices must be able to modify all data so that it is acceptable to the computer during the input phase of the operation and must be able to present data in usable form during the output phase. Second, the devices must operate quickly and efficiently in conjunction with the computer.

Conventional input devices read coded data into computers or other devices from punched cards or punched paper tape (using holes punched in various positions of the cards or tape to represent data), or from magnetic tape (using magnetized areas on the tape). In some special military applications the computer input is received from special purpose devices such as missile guidance systems or tactical display consoles.

Data may be presented at the output in printed form (English or numerals), in plotted form (such as maps and graphs), on punched cards, paper tapes, magnetic tapes, or oscilloscopic displays. Outputs in still other forms are available for special applications.

Nearly all input/output devices suffer the same disadvantages — slowness of response. Most computers can process millions of bits of data per second. Input/output devices, particularly those which require some mechanical operation, are hard-pressed to manipulate several thousand bits per second. There is, of course, a wide disparity in data exchange rates between the various devices, but the computer is faster even when the fastest of these devices are considered.

Various procedures are being used in order to more profitably utilize computer time. One such procedure, designed to minimize computer idling time, is to program I/0 cycles to run concurrently with computation. Another is to use a number of I/0 channels and provide multiplexed inputs to the computer from several I/0 devices. (Multiplexing, as used here, refers to the ability of the computer to sample the data on a number of input channels while maintaining the intelligence of the data from each channel. The rate of the multiplexing action is high enough to permit the operator of each I/0 device to retain immediate access with the computer).

Common methods for improving computer usage in so far as can be accomplished by the I/0 equipments themselves include the use of off-line devices (devices not under the direct control of the computer), use of electronic switches to multiplex several pieces of equipment on one channel, and the use of buffer storage registers in the I/0 equipment.

Buffers serve as intermediate storage devices to facilitate transfer of data between two mediums whose operating speeds are difficult, or impossible, to synchronize. It is frequently necessary to read data from cards, paper tapes, keyboards, etc., into the main (primary) computer memory. In most cases, the speed at which input devices can supply data to storage cannot be increased sufficiently to match the ability of the computer to read-in the data at electronic speeds. The same incompatibility is encountered when reading data from memory to output devices. A buffer device is therefore designed to read-in or write-out data at speeds which are compatible with both the input/output devices and the main computer memory.

Several types of buffers are in use. The simplest type is an arrangement of flip-flop registers into which data can be slowly accumulated but can be released or read-out at electronic speeds. By design, data can be read-into and out-of the registers in either serial or parallel form. The buffer storage must be capable of reading data slowly from the input device, and, at a later time, writing this data at electronic speeds into the main memory. It must also be capable of reading in data at electronic speeds from the main memory and writing this data slowly at the output device.

## BUFFER OPERATION

As previously mentioned, the input-output section of a computer handles the flow of information to and from the computer. Prior to the execution of a program, the data and instructions which comprise the progam are loaded into the computer memory. After computation is completed, the results are transmitted from memory to external equipment. The buffer or exchange operation, although program initiated, proceeds under independent control of the program. When data is transmitted, the main program initiates an automatic cycle which buffers data to and from memory. The main computer program continues while the buffering of data is carried out independently and automatically.

The computer may communicate with external equipment through independent buffer channels. The data input and output channels are paired. For example, channels 1 and 3 are input buffer channels and channels 2 and 4 are output channels. Therefore, channels 1 and 2 form a transmission link with the external equipment as do channels 3 and 4. All information enters or leaves the computer through these buffer channels. All external equipment is connected to a pair of channels; hence, more than one piece of equipment is connected to the computer via a channel. All four buffer channels may transmit information concurrently. However, only one piece of equipment can use a channel at any one instant. The computer determines by select codes and sense codes which equipment is to communicate with the computer.

The rate of data exchange is determined by the speed of the equipment in communication with the computer. Information is transmitted at a word-by-word rate. Some external equipment transmit words in serial form while the computer is equipped to accept words in parallel form. Therefore, a converter is necessary in the input-output circuits.

The converter forms a two-way conversion link between the computer and the external equipment by converting a word arranged in serial form to the parallel form used in the computer or vice-versa.

## D-C LINE DRIVERS AND RECEIVERS

The computer and the external equipment may exchange control signals and data by means of d-c line driver and d-c line receiver combinations. Basically, these drivers and receivers are a special type of NOR circuits that invert and change the logic voltage level of their inputs.

A d-c line driver accepts inputs of d-c pulses and provides amplified outputs suitable for cable transmission. The inputs are normally the logic pulse and a gating pulse. The amplitude of the output pulses from a d-c line driver will be determined by the type of external equipment used with the computer.

The d-c line receiver accepts inputs of d-c pulses and provides output pulses reduced in amplitude. This circuit inverts the logic and converts the logic voltage levels used on the interconnecting cables to the computer logic voltage level that correspond to the input level.

## TRANSMISSION CONTROL SIGNALS

A typical weapon system computer that the FTB may encounter has three basic requirements for the exchange of data: control of external equipment, activation of a buffer channel and the data transmission process itself. The data transmission process is relatively simple and is handled in a straight-forward manner. There are two types of control signals used to start or stop the normal exchange of data: data ready and data resume. The ready signal accompanies the data while resume is a return signal which indicates data received and more information may be transmitted. The computer generates a data ready signal when an output buffer channel is activated and one of the output registers holds a word. Generation of an output data resume depends upon the operation of the external equipment and indicates reception of the previous word and readiness to receive the next word. Generation of an output data ready signal also depends upon the operation of the external equipment and indicates to the computer that data is present on its transmission lines. The computer generates an input data resume signal when an input buffer channel is activated and a resume from memory indicates the previous word has been stored.

We will outline, by a simplified version, the steps the computer follows in the data exchange sequence. The exchange of control signals in the transmission of a word into the computer are:

1. Computer, by a combination of the external select and sense codes, establishes equipment from which it is to receive information.
2. Computer activates input buffer channel. This channel remains on until transmission is complete.
3. Equipment places a word in the channel and produces input data ready signal.
4. Computer, when it has accepted the word, produces input data resume signal.
5. Input data resume signal causes the equipment to turn off its input data ready signal and to prepare another word for the computer.
6. Removal of the input data ready signal causes the computer to turn off its resume signal.

When steps 3 through 6 are completed, the buffer action signal is dropped and the buffer operation is terminated.

The following is an outline of the exchange of control signals in the transmission of one word out of the computer:

1. Computer, by a combination of external select and sense codes, establishes equipment to which the word is to be sent.
2. Computer activates an output buffer channel, this channel remains on until transmission is complete.

3. Computer places the word in output register.
4. Computer generates an output data ready signal which indicates to the equipment that data is available.
5. Equipment accepts output data ready signal and the word at its own rate. When it accepts output data ready signal, it produces an output data resume signal which it returns to the computer.
6. Computer accepts output data resume signal and turns off its output data ready signal.
7. Removal of the output data ready signal in the computer causes termination of the output data resume signal within the equipment.

When steps 3 through 7 are completed the output buffer action signal is dropped and the buffer operation is terminated.

## COMPUTER OUTPUT CIRCUITS

The output circuitry of the computer consists of registers and their associated control circuits. The output registers provide temporary storage for all information leaving the computer. A word to be transferred is selected from memory and gated into an output register by the buffer sequence control circuits. The stored words are then transferred through d-c line drivers to d-c line receivers in the external equipment.

# CHAPTER 7

# INERTIAL DEVICES

Inertial guidance is defined as: "A guidance system that guides the missile along a predetermined flight path where the position of the missile is constrained to that path after launch by devices wholly within the missile and totally independent of external sources of information." By definition, it is apparent that the missile contains all the components necessary to the operation of the guidance system and that the missile be supplied, prior to launch, with all the information it needs to hit the target.

Future target position with respect to the launch point must be known. And it follows that ship position and motion at the instant of launch must be established with a degree of accuracy at least equal to the required terminal accuracy of the missile. Where the missile time of flight is appreciable, the difficulty of computing a missile path to future target position and measuring missile motion, position, and attitude with respect to the computed flight path is quite formidable. These measurements must be made with great precision for they spell the difference between a useful or useless weapon system. For example, a missile may be traveling at 15,000 feet per second when the reentry body is released, yet a velocity error of only 1 foot per second produces an impact error of approximately one-half mile in range.

The flight path followed by a Fleet Ballistic Missile (FBM) is dependent on measurements of missile motions. These motions are detected and measured by a group of sensors in the missile guidance system. Basically two types of sensors are used: gyroscopes which detect angular displacements of the missile about the flight path and accelerometers which detect changes of linear motion along the flight path. Both types of sensors are inertial devices whose operating principles are governed by the physical laws of motion. Therefore, this chapter has a threefold purpose: it summarizes the physical laws involved, it describes in detail the operating principles and the general arrangement of the inertial devices, and it emphasizes the applications of these devices in the FBM equipment. The inertial devices are the dynamic heart of the FBM system and as such an understanding of them is essential to the FTB.

## MOTION

Relative motion is the motion of objects with respect to each other. This is the type of motion we observe. For example, assume you are in a car traveling 50 miles per hour alongside a large truck traveling in the same direction and at the same speed. It would be difficult to sense your speed by observing the truck since the relative speed is zero. By shifting your sight to the roadside you can obtain an idea of the speed of your car with respect to the earth. However, the earth is not stationary; it is in rapid motion as it travels in space with our solar system, orbits around the sun, and rotates on its axis. Therefore we must establish a reference from which we can measure relative motion. Conventionally the terms "speed," "velocity," and "condition of rest" are measured with respect to the earth and the space about it where the Newtonian laws of motion are valid. This area is called inertial space.

In general there are two types of motion; linear and angular. Linear motion is any motion in a straight line and is considered as a motion of translation of the object's center of gravity. Angular motion is any motion not in a straight line and is considered as a motion of rotation about an axis. We will consider linear motion first.

### LAWS OF MOTION

Newton's laws of motion are basic laws of physics. Even though the laws are fundamental, they are important enough to the study of the inertial devices used in the FBM to be included here.

Newton's first law of motion states: "A body at rest remains at rest, and a body in motion continues to move at a constant speed along a straight line unless acted upon in either case by an unbalanced force."

The first statement in this law is apparent from experience. The second statement is not quite so apparent since in everyday experience friction is always present to resist motion. However, if all retarding forces could be removed, an object set in motion would continue to move indefinitely at a uniform speed unless acted upon by an unbalanced force. A force is a push or pull exerted upon an object. Thus energy is applied to the object. And it follows that the forces acting on an object at rest or in uniform motion must be equal and opposite, or in other words, are in balance and will cancel each other. If these forces are not in balance the object will accelerate.

Newton's second law of motion states: "An unbalanced force acting on a body causes the body to accelerate in the direction of the force, and the acceleration is directly proportional to the unbalanced force and inversely proportional to the mass of the body." This law in formula reads:

$$a = \frac{F}{m}$$

where "a" equals acceleration, "F" equals the unbalanced force acting on the body, and "m" equals the mass of the body. The second law of motion establishes mathematically the relationship between the three factors involved with motion.

Newton's third law of motion states: "For every action there is an equal and opposite reaction, and the two are along the same line." This law deals with two bodies and forces. For example, a football when kicked is momentarily distorted and a restoring force is set up in it which reacts upon the kicker's foot. The action, (motion of the kicker's foot), is exerted on the ball; while the reaction, (restoring force in the ball), is applied against the kicker's foot. It is the reaction force that propels the ball into flight. The action and reaction are exerted on separated bodies and therefore cannot cancel each other. In order for two forces to cancel, they must be exerted on the same body. This principle is fundamental to reaction type motors, such as jet and rocket motors.

### Inertia

You may think of inertia as the opposition offered by a body to any change of motion; that is, an unbalanced force is required to give it linear acceleration. The definition of inertia is in fact a restatement of the first law of motion. The property of inertia implies a broader concept of the definition of mass than mere quantities of matter. You may think of mass as the property of an object by virtue of which it possesses inertia. Let's examine the relation between the mass and the weight of an object. For any given mass the gravitational attraction of the earth varies with the geographical position or distance from the earth's center. This attractive force exhibited by the earth is called weight. As a result of this variation in the weight of matter, it is necessary to use the following expression to define mass:

$$M = \frac{W}{g}$$

where "M" is mass, "W" is the weight, and "g" is the acceleration produced by the earth's attraction. Both "W" and "g" vary in such a manner as to keep "M" constant. It follows then that weight is a force acting on matter and mass is a property of matter.

### Momentum

From the discussion of inertia and the first law of motion it can be deduced that a body in motion possesses the tendency to remain in uniform motion. This tendency or property is called momentum, which is defined as "the product of the mass of a body and the body's velocity." It might be called "the quantity of motion" of a body and is the amount of kinetic energy in the body. Kinetic energy is sometimes referred to as the energy of motion. Momentum is a vector quantity and has the same direction as the velocity vector.

## ANGULAR MOTION

A body rotating about a fixed axis, such as a flywheel on a motor shaft, does not move from one point to another along a straight line and consequently its motion is not linear. Different points on the flywheel describe concentric circles about the rotational axis. If the rotary motion is constant we can compute angular speed by the formula:

$$\text{angular speed} = \frac{\text{angle sweep through}}{\text{time}}$$

or symbolically:

$$\omega = \frac{\theta}{t}$$

where the Greek letter omega ($\omega$) stands for angular speed, the Greek letter theta ($\theta$) stands for angular displacement, and "t" stands for time.

A rotating body will continue to turn about a fixed axis at a constant angular speed unless acted upon by an unbalanced torque. Notice the similarity between this statement and the first law of motion. You can consider torque as the angular equivalent of force. Force acts in a straight line at or on a point, whereas torque occurs in a plane and is referred to as being applied about an axis. A torque is equal to the product of the force and the perpendicular distance from the axis of rotation to the line of action of the force. Expressed as a formula:

$$T = Fr,$$

where "T" equals torque, "F" equals force, and "r" equals the perpendicular distance or radius through which the torque is exerted. This radius is sometimes called the lever arm distance.

A torque applied to a rotating body will produce angular acceleration, which is symbolized by the Greek letter alpha ($\alpha$). Angular acceleration is directly proportional to the torque exerted and indirectly proportional to the resistance the body offers to a change in its angular motion. This is in accordance with the second law of motion. But a torque is applied about the rotational axis through the lever arm distance. Consequently, the resistance to a change in the angular motion is affected by the mass of the body, the distribution of the mass, and the lever arm distance.

### Moment of Inertia

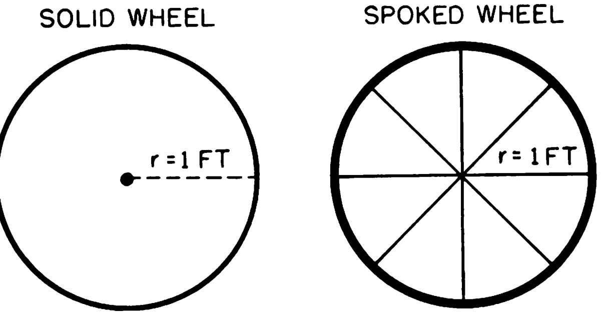
Moment of inertia is a measure of the torque needed to bring about a change in the motion of a rotating body. Moment is defined as the tendency of energy acting on a body to produce motion, while inertia is the tendency of a body to resist a change in motion.

Moment of inertia, which is symbolized by the letter "I", considers both the energy and the resistance involved in a change of motion of a rotating body. In linear motion inertia is considered to be along a straight-line axis and, therefore, resistance to a change in motion can be computed by using the mass of the body. But this is not true of a rotating body whose axis of motion does not coincide with the lines of force. The distance between the point where the force is applied and the location of the resistance can be plotted along a radius of the body. Thus we can consider this distance in somewhat the same manner as we do leverage.

MOMENT OF INERTIA can be demonstrated with two weights (one heavy and the other light), a board, and a fulcrum, arranged in the manner of a seesaw. To balance the two weights, we have to place the heavy weight near the center and the light weight near the end of the board. This makes the light weight more effective by being farther out from the fulcrum and having greater leverage. If we have two equal weights, we can make one outbalance the other by putting one farther out on the board. The same principle applies to two rotors of equal weight. The rotor, having its weight distributed "farther out on the board," has the greater moment of inertia.

Moment of inertia is often expressed in terms of the aggregate mass of the body and a single fictitious radius called the radius of gyration. The radius of gyration of a body is defined as the distance from the body's axis of rotation to a point at which the entire mass of the body may be considered concentrated without altering the moment of inertia.

Figure 7-1 shows two wheels, both have a radius of one foot and are of equal mass. The mass of the solid wheel is concentrated closer to the rotational axis than the mass of the spoked wheel. Thus the spoked wheel has a greater radius of gyration and a greater moment of inertia. To produce the same angular acceleration in both wheels a greater torque must be exerted on the spoked wheel. Although both wheels will have equal acceleration, it stands to reason that the spoked wheel must possess a greater angular momentum since a greater torque was exerted.



177.40
Figure 7-1.—Effect of weight distribution.

## Angular Momentum

Angular momentum is equal to the product of the moment of inertia (I) of a body and its angular velocity ($\omega$). There is a similarity between linear and angular momentum in that both are a measure of the amount of energy in a body due to its motion. Just as an unbalanced force exerted on a body causes a change in linear momentum, an unbalanced torque applied to a body will cause a change in angular momentum.

There can be no change in angular momentum unless an unbalanced torque is applied. In other words, the product $I\omega$ will remain constant unless a torque is exerted on the body. Some rather odd effects are explained by this fact. For example, an ice skater in a rapid spin with arms extended can increase the angular velocity of the spin by bringing his arms in toward his body. A torque has not been applied but the spin velocity has increased because the moment of inertia has been reduced. Thus the angular momentum has remained constant.

It is apparent that a rotating body's rigidity about its spin axis is proportional to its angular momentum. Hence an increase in angular velocity or in the moment of inertia will result in a rotating body offering more resistance to an unbalanced torque tending to change its spin axis. However, it should be realized that an unbalanced force acting through a rotating body's center of gravity will cause a linear acceleration and will not affect its angular momentum. This linear motion is called translation.

## Centrifugal and Centripetal Forces

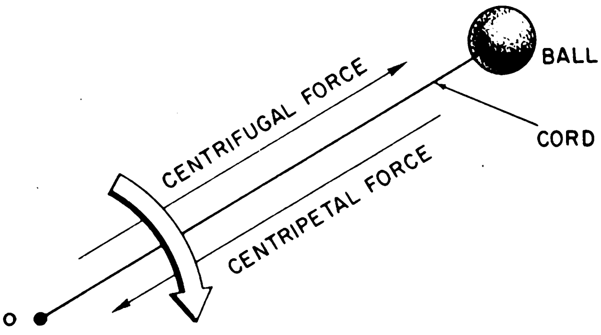
In accordance with Newton's second law, a body in motion will not deviate from a straight line unless a lateral force is exerted upon it. When a locomotive arrives at a curve in the track, its forward motion causes the flanges on its wheels to press outwardly against the edge of the outer rail; and, conversely, the rail presses inwardly against the flanges. The locomotive changes direction as a result of this inwardly directed force and follows the curved track.

The lateral force required for motion along a curve also may be illustrated by a ball attached to a cord. (See fig. 7-2.) When the ball is whirled around at the end of the cord, the ball pulls outwardly, exerting a centrifugal force on the cord. The result of the centrifugal force is to cause the cord to become taut and exert an inward pull, centripetal force, upon the ball.

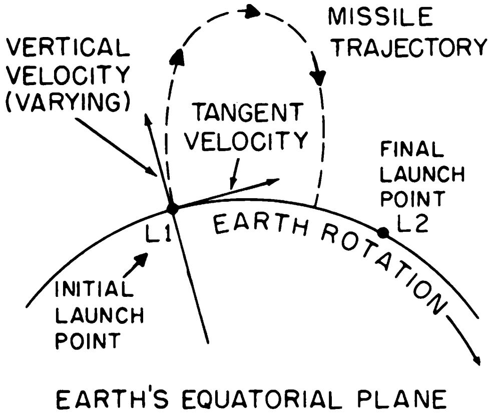
The ball, traveling along a circular path at constant speed, is pulling against the cord with a constant force directed outwardly along a radial line from the center of its path of rotation. Since for every action there is always an equal and opposite reaction, the cord exerts an equal inward force upon the moving body.

Thus, any motion along a curve involves centrifugal and centripetal forces which are equal and opposite, and both forces are exerted in the plane in which the curve lies. However, although equal, these forces cannot balance each other because they are not exerted upon the same object.

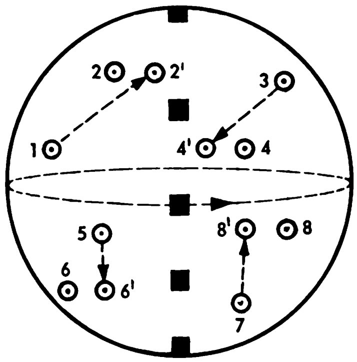
An unbalanced force always produces acceleration. The centripetal force acting upon a body in circular motion continually accelerates it



177.46
Figure 7-2.—Forces acting on a ball whirled around at end of cord.



177.47
Figure 7-3.—Coriolis Effect.



33.136
Figure 7-3A.—Coriolis Effect in the Northern and Southern Hemispheres.

toward the center of the circle. The body moves in a circle as a result of this inward motion combined with its forward motion.

Note the fact that when a body follows a circular path at constant speed, its velocity is changing continually, not in magnitude but in direction. Remember, velocity is a combination of speed and direction—a vector quantity.

GEOPHYSICAL PROPERTIES

The prescribed flight path of a missile is within the sphere of influence of the earth. A network of forces exerted by the mass and motions of the earth act on the missile. In order for the missile to remain in its prescribed flight path, the inertial devices in the guidance system must be aligned to a reference point and compensations must be made for the effects of these forces. We will consider the natural forces acting on the missile.

Coriolis Effect

If a missile is launched directly upward from a point on the equator (fig. 7-3), it would move up and to the east, reach a zenith, and fall back to earth. But it would land to the west of the launch point. The reason it falls to the west of the launch point is that in order to move east at the same rate as the launch point moves due to the earth's rotation, the missile would have had to increase the eastward component of its velocity because it is further from the center of earth's rotation as it rises. Since the missile could not do this, it fell behind the launch point as the earth rotated in an easterly direction. It is as though the missile had experienced an apparent acceleration to the west. This apparent acceleration is caused by what is known as the coriolis effect.

The coriolis effect is based on the fact that different points on the earth's surface have different angular velocities around the axis of the earth. In figure 7-3A the object at the equator has a velocity of about 1000 miles per hour around the earth's axis. The two objects between the equator and the poles will have a considerably smaller velocity. The objects at the poles will have zero velocity.

If we fire a missile from point 1 toward point 2 and do not correct for the coriolis effect, the missile will be deflected to its right as shown by the dotted lines. In this case, the velocity of the launching point is greater than that of the target. The launching point component of the velocity will cause the missile's deflection to the right, and cause it to strike at point 2'.

Now assume that we fire from point 3 to point 4, again failing to correct for the coriolis effect. The missile will again be deflected to its right, landing at point 4'. In this case, the launch point has a smaller angular velocity than the target point.

From the foregoing, we can say that if the coriolis effect is not corrected for, the missile will be deflected to its right in the Northern

Hemisphere due to the differences in angular velocity of points at different latitudes.

In the Southern Hemisphere, the effect is reversed; that is, the missile is deflected to its left. This can be seen when firing from point 5 toward point 6 in the figure. The higher velocity at point 5 (relative to point 6) will cause the missile to be deflected to its left, landing at point 6'. If we fire in a northerly direction in the Southern Hemisphere, the missile will still be deflected to its left as shown by points 7, 8, and 8'.

Therefore, we can say that if the coriolis effect is not corrected for, a missile will always be deflected to its left in the Southern Hemisphere.

Since the angular velocity imparted to the missile varies with latitude, the magnitude of the coriolis effect is latitude dependent. The effect is also proportional to missile horizontal velocity. Thus the effect will vary along a flight path having a latitude component or a varying missile horizontal velocity.

### Gravity

The law of universal gravitation states: "Each particle of matter attracts every other particle with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them." Thus bodies fall to the ground because of the attraction between the earth and the bodies. This attraction is the force of gravity, (symbolized by the letter "g"), and causes a body to accelerate while falling. Neglecting air resistance, all bodies fall with the same acceleration. At the surface of the earth, g is equal to 32.2 feet per second squared. This figure varies slightly at different locations on the surface of the earth due to its shape.

The attraction which the earth exerts upon a body extends to every particle of matter of which the body is composed. Thus, the weight of a body may be considered as an aggregation of parallel forces acting upon the individual particles in the body. If these parallel forces are replaced with their resultant, this single force is exactly equivalent to them.

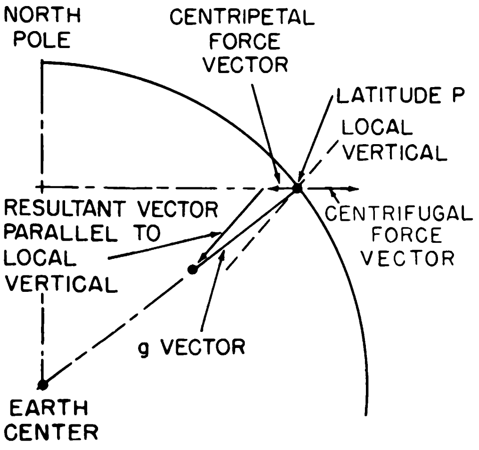
For any given object there is a particular point through which the resultant of the weight forces will always pass regardless of the orientation of the object. This point is called the CENTER OF GRAVITY (C.G.) of the body. Hence, the weight of an object, although actually a system of parallel forces acting upon all its component parts, can be correctly represented by a single force acting downward at the center of gravity.

The gravitational force provides us with a convenient reference to align the inertial devices in the missile guidance system. Assume that the earth is spherical in shape, its mass has a uniform density, and it is not in motion. Under these assumptions the center of gravity of the earth would coincide with its geometric center. The gravitational force exerted on the missile would be directed at all times toward a point located exactly at the earth's center. Thus a plumb bob or pendulum that is free to align itself with the gravitational force would point toward the center of the earth. Therefore, a line through the center of the pendulum would be in the true vertical with respect to a line tangent to the surface of the earth. Once the vertical plane is established we could use it to orient the missile guidance system with respect to the earth.

Unfortunately, the foregoing assumptions are completely false. First of all, we know the earth is not motionless. The rotation of the earth on its polar axis once a solar day is the only motion of the earth we will consider. The other motions of the earth do not greatly affect the missile guidance system.

Particles at all points on the earth other than on the polar axis will experience a centrifugal force as a result of the earth's angular velocity. This centrifugal force is greatest at the equator, diminishing to zero at the poles. The combined effect of this centrifugal force and the gravitational force is to distort the earth from a spherical to an oblate (flattened at the poles) spheroidal shape known as an ellipsoid. The polar diameter of the earth is somewhat less than the equatorial diameter. Moreover, a pendulum not on the earth's polar axis would experience both the attraction of gravity and the centrifugal force. The pendulum would not indicate the true vertical but rather the local vertical.

In figure 7-4 a pendulum is located on the surface of the earth at latitude P. The gravitational force vector g is plotted toward the center of



177.48

Figure 7-4. — Geometry of the local vertical.

the earth. We can consider this vector to be aligned with the true vertical with its tail toward the true zenith and its head indicating the true center of the earth. Next we will plot the centrifugal force vector indicating the direction and magnitude of this force on the pendulum. However, we are interested in the reaction of the pendulum, and as you know, the centripetal force is directed toward the axis of rotation and is equal and opposite to centrifugal force when the pendulum is following a curved path. Therefore, we will plot the centripetal force vector and determine the resultant of this vector and the g vector. The resultant vector indicates the local vertical if the density of the earth's mass is uniform.

The centrifugal force vector varies with latitude, being zero at the poles, and axis of earth rotation, and maximum at the equator where the velocity is greatest. At the equator it is parallel to the gravitational force but oppositely directed, so that the local vertical is not deflected from the true vertical. (The magnitude of resultant vector, of course, would be less than that of the g vector.) It can be shown that the deflection is greatest in the vicinity of latitude 45 degrees.

Since the shape of the earth is not spherical, the poles are closer to the earth's center of gravity than is the equator. Therefore, the magnitude of gravitation is greater at the poles. This effect is slight when compared to the effects of centrifugal force.

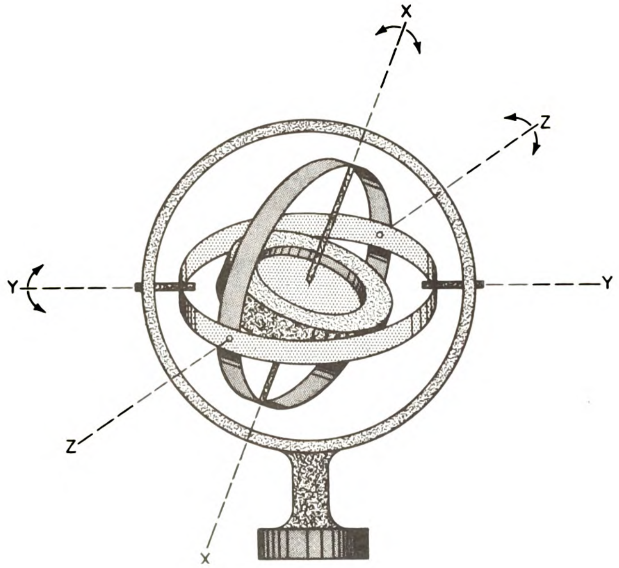
In our discussion describing the determination of the local vertical we did not consider variations in the density of the earth's mass. The pendulum would be deflected toward the more dense regions in its vicinity. An additional complication is the influence by other spatial bodies on the complex pattern of gravitation over the earth. While this effect is small, it does influence the degree of deflection of the pendulum from the true vertical.

The conclusion we can draw from the foregoing discussion is that a pendulous device will align itself with a local vertical rather than the true vertical. Now we must consider how this will affect the inertial guidance system in the missile. The reference plane containing the local vertical is only valid at the point where it is established. On the other hand, the FBM must travel great distances along a prescribed flight path to the target. The prescribed flight path is computed within a frame of reference that is established with respect to the local vertical, which is determined in the submarine at the launch point. Simultaneously, the reference plane is established in the FBM guidance system. The missile's inertial devices maintain this reference plane throughout flight and thus are capable of measuring the missile's attitude and motion with respect to the prescribed flight path, and to the reference plane. It should be emphasized that the reference plane containing the local vertical is not the only reference plane used in FBM guidance. We will describe the frames of reference used in the FBM system in the next chapter.

## GYROSCOPES

The gyroscope, commonly called a gyro, has existed since the first electron was sent spinning on its axis. Electrons spin and show all the characteristics of a gyro, and so does the earth which spins about its polar axis at over 1000 miles per hour at the equator. The earth's rotation about its axis provides the stabilizing effect that keeps the North Pole pointed within one degree of Polaris (the North Star).

Any rapidly spinning object — a top, wheel, an airplane propeller, or a spinning projectile — is fundamentally a gyroscope. Strictly speaking, however, a gyroscope may be defined as a mechanical device containing a spinning mass



12.137
Figure 7-5.—Gyro model, universally mounted.

which is universally mounted, that is, mounted so it can assume any position in space. Figure 7-5 shows a model of a gyro. As you can see, a heavy wheel (rotor) is mounted so that its spin axis is free to turn in any direction. The wheel can spin about axis X, it can turn about axis Y, and finally turn about axis Z. With this mechanical arrangement the spinning wheel can assume any position in space.

BASIC PROPERTIES OF GYROSCOPES

Gyroscopes have two properties which make them useful in weapon control:

1. The axis of rotation (spin axis) of the gyro wheel tends to remain in a fixed direction in space if no force is applied to it (rigidity).

2. The axis of rotation has a tendency to turn at a right angle to the direction of an applied force (precession).

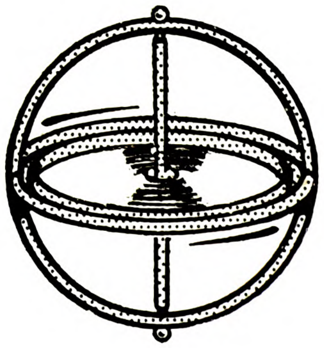
The idea of maintaining a fixed direction in space is simple to illustrate. When any object is spinning rapidly, it tends to keep its axis pointed always in the same direction. A toy top is a good example. As long as it's spinning fast, it stays balanced on its point. Because of its gyro action, it resists the tendency of gravity to change the direction of its axis. You can think of many more examples. A bicycle is easier to balance at high speed than when it's barely moving. At high speed, the bicycle wheels act as gyros, and tend to keep their axes parallel to the ground.

Note that it's easy to MOVE the axis as long as you keep it pointing in the SAME DIRECTION. The gyro resists only those forces that tend to change the direction of its axis. In a bicycle, since the axis of rotation is horizontal, the wheels will resist any force that tends to tilt the wheel over or turn it.

If you can obtain a gyroscope top, you can do some instructive experiments with it. Hold the gyro top with its axis vertical (fig. 7-6) and start it spinning. As long as it is spinning fast, it will stay balanced. You can balance it on a string or on the point of your finger; the axis will stay vertical as long as the top is spinning fast.

Now stop the gyro top and turn its axis horizontal. Start it spinning again and balance one end on a pivot. (See fig. 7-7.) If the top is spinning fast, it won't fall. Its axis will stay horizontal, resisting the tendency of gravity to change its direction. But while the gyro will resist the force that gravity applies to it, it will still RESPOND to that force. And it responds by moving its axis at a RIGHT ANGLE to the APPLIED force.

Figure 7-8 is another view of the same gyroscope. Its far end is still balanced on the pivot. Gravity is pulling down on the gyro. If the gyro rotor is turning in the direction shown



4.98
Figure 7-6.—A gyroscope top.

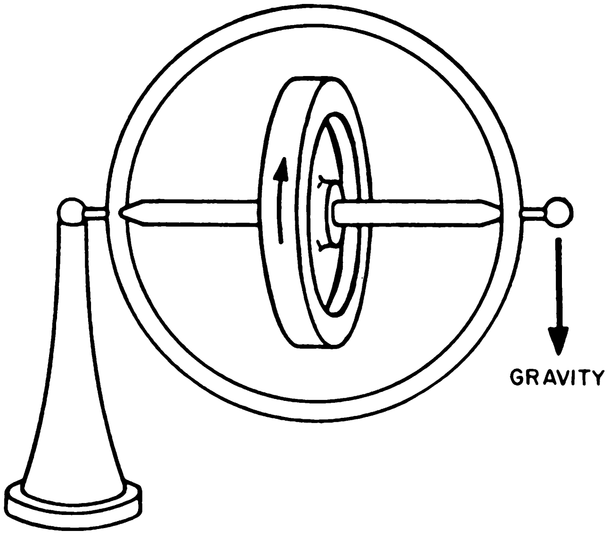


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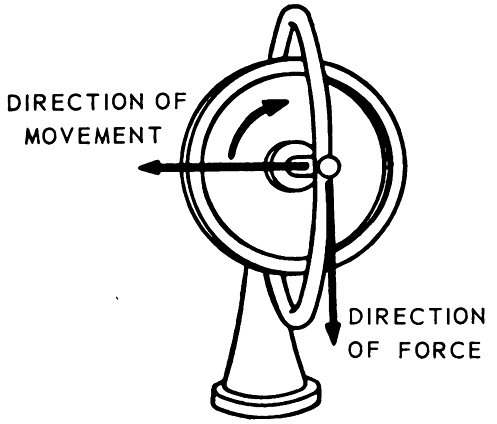
Figure 7-7.—Gyro top with axis horizontal.



4.100

Figure 7-8.—Gyro precession.

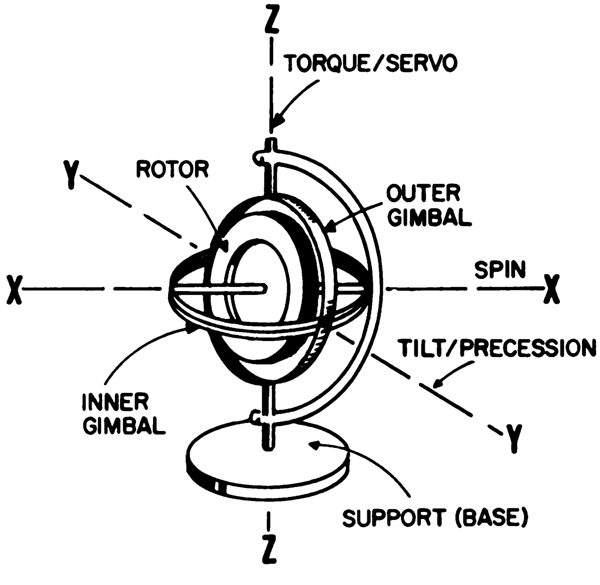
by the arrow, then the near end of the frame will turn to the left. (If the rotor is turning in the opposite direction, the frame will turn to the right.) The axis will stay horizontal, but the gyroscope will respond to the force of gravity by rotating around the pivot.

Gyro action may be summarized in this fashion: A spinning gyro tends to keep its axis pointing in the same direction. This is called rigidity. If you apply a force that tends to change the direction of the spin axis, the axis will move at a right angle to the direction of the applied force. If the axis is horizontal, and you try to tilt it, the axis will turn. If the axis is horizontal, and you try to turn it, the axis will tilt. This second characteristic of a gyro is called precession.

BASIC GYRO ELEMENTS

The gyro shown in figure 7-9 is a basic universally mounted gyro. The components are: rotor, inner gimbal, outer gimbal, and base or support. The three major axes of any gyro are the spin, torque and precession. The spin axis is, of course, the axis in which the rotor spins. The torque axis is the axis about which the disturbing force is applied. The precession or tilt axis is the axis the gyro turns about as a result of the force applied to the torque axis.

There are several ways of naming the axes of a gyro. The name assigned an axis is usually taken from the reference line or plane it has established. Some of the names are: north-south, east-west; vertical, horizontal; roll, pitch, and yaw; input, output; torque, sensitive.



12.138

Figure 7-9. — Basic universally mounted gyro.

The gimbals are devices which permit the rotor to incline freely in any direction and retain that position when the support is tipped or repositioned. Note that in figure 7-9 the support may be moved about all three axes without the rotor position being disturbed.

As you know, gravity is a force that acts along parallel lines upon each particle of matter that makes up the gyro. Each force acts independently of all other forces, but force is a vector quantity having both a direction and a magnitude. Therefore, we can plot a resultant of the forces of gravity acting on the gyro. The magnitude of this single force is exactly equivalent to the separate parallel forces. Its point of application is called the center of gravity. In order to have a balanced gyro the center of gravity must be located at the intersection of the three axes of the gyro.

## Rigidity

As you know, a gyroscope is a spinning body that tends to keep its spin axis rigidly pointed in a fixed direction in space. What do we mean by FIXED DIRECTION IN SPACE? A fixed direction on earth is by no means fixed in space, because the earth turns once on its axis every 24 hours. It makes a complete revolution around the sun every year. And the sun itself is moving, taking the earth and the other planets with it. Because of these motions, the expresssion "fixed direction in space" as used here is theoretical. If that were an exact statement, our universe would have to be unaccelerated and therefore nonrotating. But for all practical purposes we can say this: a line from the earth to a distant star is a fixed direction in space. If the spin axis of a spinning gyro is pointed at a distant star, it will remain on the star as the earth turns.

Three factors determine a gyro's rigidity, or the strength with which it resists any external force tending to displace its rotor spin axis. These factors are: weight of its rotor, distribution of this weight, and rotor speed.

We can consider the gyro as an enclosed mechanical system. The energy in the system is equal to the input energy. Hence the energy necessary to spin the gyro rotor is contained in the rotor as angular momentum. The heavier the gyro rotor, the larger the torque necessary to spin it, and the greater the angular momentum of the rotor. If we have two rotors with identical shapes but of different weights spinning at the same velocity, the heavier of the two will be more rigid in its spin axis since it contains the greater angular momentum.

To understand the effect of weight distribution in a rotor of a gyro, consider two rotors of the same weight, with the diameter of one, half that of the other. Now, when we spin both of these rotors at the same speed, we find that the rotor with the greater diameter is much more rigid than the one with the smaller diameter. Next we find that we can make both rotors equally rigid by causing the rotor with the smaller diameter to spin faster than the larger rotor. Thus rigidity is dependent upon both speed and distribution of weight. The weight of the larger rotor being farther away from the axis of spin causes it to be more effective for rigidity. In physics it is said that the weight of the larger diameter rotor has the greater "moment of inertia."

## Precession

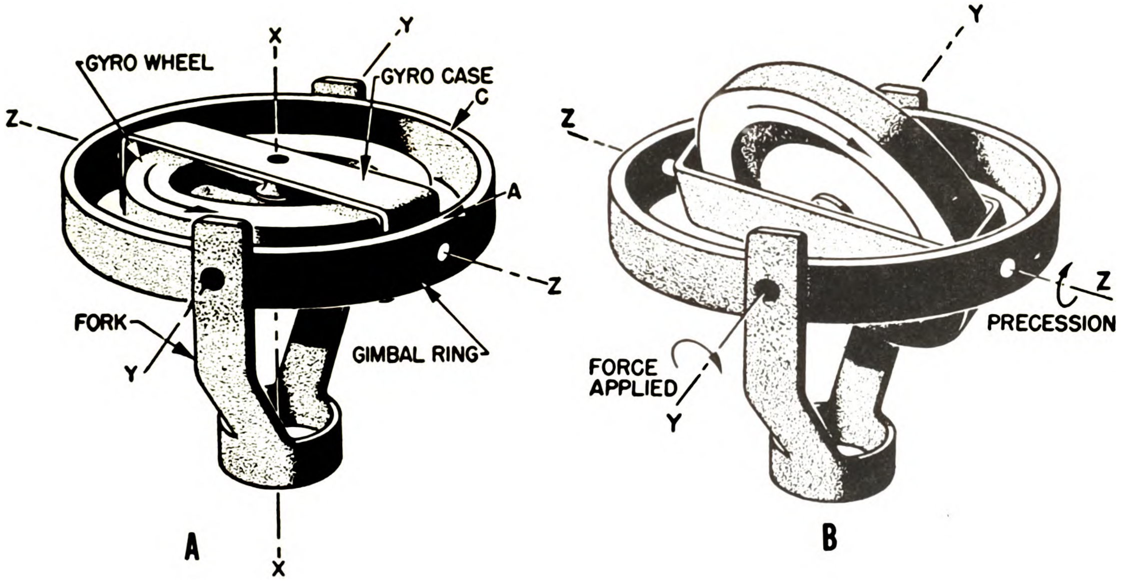
A gyro is a true space device in regard to its ability to maintain its axis in a fixed direction. To provide useful information its spin axis must be related to some reference, usually the earth's surface. This is done by using the second fundamental property of a gyro—precession. The gyro is precessed until its spin axis is pointed in the desired direction. So far we have covered precession in very general terms. We will cover this action in more detail.

Precession can be shown by using the models in figure 7-10.

A gyro wheel is mounted so that it is free to align its spin axis in any direction. Here the wheel rotates in a flat loop called the gyro case or inner gimbal. The gyro case is pivoted in the gimbal ring and the gyro can swing about the Z axis. The gimbal ring itself turns on pivots which connect it to the fork (support), permitting the gyro to tilt from side to side about the Y axis.

Regardless of how the fork is placed, the spinning gyro wheel is free to lie in any given plane. That's why it is called a free gyroscope in this mounting.

To show the effect of precession, push down on the gimbal ring at point A at the nearer end of the Z-Z axis. (See fig. 7-10A.) You would expect the ring to tilt around the Y-Y axis. Instead of rotating about the Y-Y.axis as you



A. GIMBAL MOUNTING
B. PRECESSION

12.141

Figure 7-10.—Gyro action.

might expect, however, the gyro case will turn about the Z-Z axis. You can see the effect of precession in figure 7-10B.

Similarly, going back to figure 7-10A, suppose you push sideways on the top of the X-X axis (the spinning axis of the gyro), trying to rotate the wheel around the Z-Z axis. Then, instead of rotating about the Z-Z axis, the gimbal ring will turn around the Y-Y axis.

If you push down at point C on the gimbal ring (fig. 7-10A) midway between the Y-Y and Z-Z axes, you will find that the gimbal ring rotates around the Y-Y axis, and that the gyro case rotates around the Z-Z axis. The total effect causes the gyro wheel to turn around a line lying from point C through the center of the gyro wheel.

Here's a rule that applies to all spinning gyros: THE GYRO WILL ALWAYS PRECESS AT RIGHT ANGLES TO THE DIRECTION OF THE APPLIED FORCE. Look at figure 7-10A again. If you keep pushing down on the gimbal ring at point A, the gyro case will keep turning until the spin axis of the gyro wheel is horizontal. Then there will be no further precession. At this point the gyro wheel is spinning in the same direction in which the applied force is pushing.

Here's another rule: A GYRO ALWAYS PRECESSES IN A DIRECTION TENDING TO LINE ITSELF UP SO THAT ITS ROTOR SPINS IN THE SAME DIRECTION THAT THE APPLIED FORCE IS TRYING TO TURN IT. In other words, the spin axis chases the torque axis. When the two come into coincidence, precession no longer takes place.

It should be noted that most forces, when applied to the gyro mounting, do not cause precession. For instance, you can swing the fork around in any direction, and the motion will merely be taken up in the Y-Y and Z-Z axes. Similarly, a force applied lengthwise along one of the axes will have no effect. ONLY THOSE FORCES TENDING TO TILT THE GYRO WHEEL ITSELF WILL CAUSE PRECESSION.

Let's consider further the important characteristic of gyroscopic precession, using another method to illustrate this fundamental property.

As it is impossible to make bearings entirely free of friction, in most gyros friction is kept to a minimum, and the rotors are designed to have a great deal of rigidity. Whatever friction remains is small in comparison to the great rigidity of the heavy, rapidly spinning rotor, and its effect upon the gyro is extremely slight.

An operating gyro will resist a force which attempts to change the direction of its spin axis, but it will move in response to such a force or pressure. The movement is not a direct one in response to the force; it is a resultant movement. The gyro axis will be displaced, not in the direction of the applied force, but in a direction at right angles to the applied force, and in such a way as to tend to cause the direction of the rotation of the rotor to assume the direction of the torque resulting from the applied force.

For a given force, the rate of precession is governed by the weight, shape, and speed of the wheel. These factors are the same as those that determine the rigidity of a gyroscope. Therefore, it is reasonable to assume that there is a relationship between the rigidity of a gyroscope and the rate at which a given force will cause it to precess. Such a relationship does exist. The greater the rigidity of the gyroscope, the more difficult it is to cause precession, and the less the precession for a given force will be.

The location of the precessional axis depends upon the direction in which the gyro rotor is spinning. Precession is the resultant of two forces: angular momentum (gyro rigidity) and the applied torque. Since precessional displacement s a resultant and angular momentum is in the direction of spin, the precessional axis is always offset from the applied torque axis in the direction of spin.

The forces acting on a gyroscope may be represented graphically as acting on the rotor tself, spinning freely in space, with a plane containing each of the axes of freedom.

For example, when a force is applied upward n the inner gimbal, as shown in figure 7-11, he force may be visualized as applied in an arc bout axis Y-Y until it contacts the rim of the otor at F, as in figure 7-12. The effect roduced by the force is equivalent to that roduced by a force applied upward to the inner

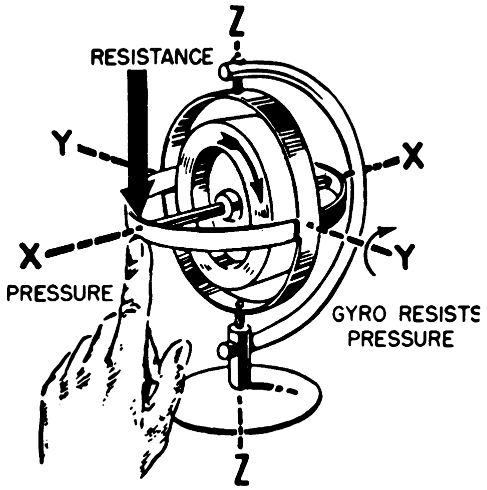


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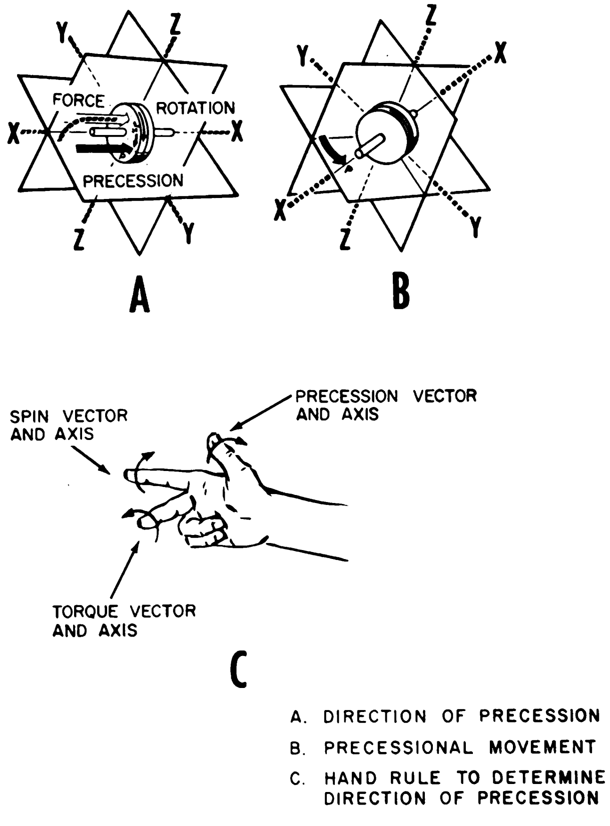
Figure 7-11. — Force applied to a gyro.



12.143

Figure 7-12. — Rules of precession.

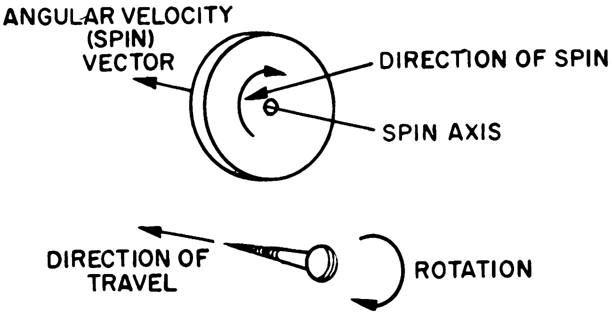


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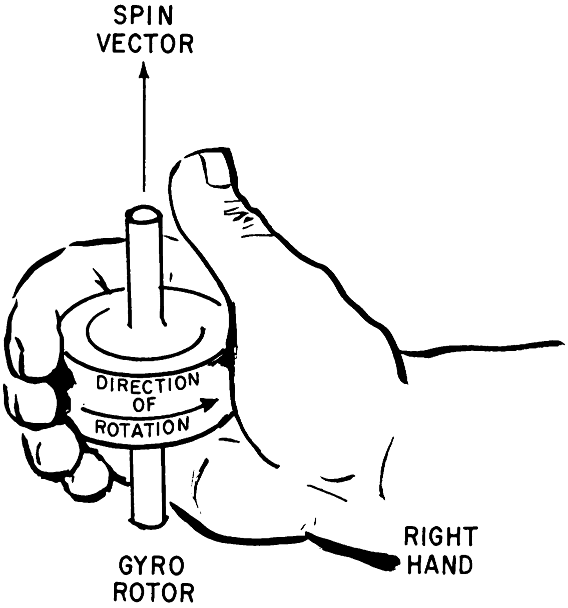
Figure 7-13.—Vector lines of action (direction).



175.35
Figure 7-14.—Determining spin vector direction.

gimbal. The force at F is opposed by the resistance of gyroscopic inertia, preventing the rotor from being displaced about axis Y-Y. With the rotor spinning clockwise, the precession will take place 90° ahead in the direction of rotation at P, as in figure 7-12. The rotor turns about axis Z-Z in the direction of the arrows at P, as in figure 7-12.

HAND RULES.—Rotational quantities such as angular velocity and torque can be represented by a vector. The length of the vector is proportional to the magnitude of the rotational quantity. The vector's line of action (direction) is along the axis of rotation and in the direction that a right-hand screw would travel if it is rotated in the same direction as the rotational quantity. For example, a gyro rotor's spin vector is perpendicular to the rotor's plane of rotation (along the rotor's spin axis). When the rotor spins in a clockwise direction the screw would move into the rotor when moved in the clockwise direction, as shown in figure 7-13. If we reverse the rotor's direction of spin, the screw would move out of the rotor when moved in the counterclockwise direction.

The motions of a gyroscope can be analyzed by three basic vector quantities: (1) spin, the angular velocity of the gyro rotor, (2) torque, the rotary motion applied to change the direction of the rotor axis, and (3) precession, the resulting angular velocity of the rotor axis when torque is applied.

All three motions are rotary (angular) and can be represented by vectors which point in such a direction that when looking in the direction of the vector the rotary motion is clockwise.

A convenient rule for determining the direction of procession is by the use of the fingers of the right hand. This method will not be new to you because you used a similar means to demonstrate the motion of a conductor in a magnetic field when you studied Basic Electricity, NAVEDTRA 10086-B.

The three vectors listed above may be represented by arranging the thumb, forefinger, and middle finger of the right hand mutually perpendicular as shown in figure 7-12. The thumb points in the direction of the precession vector, the middle finger points in the direction of the torque vector, and the forefinger points in the direction of the spin vector. You can consider these vectors as the axes about which angular motion takes place. If you look in the direction of the pointed fingers and thumb you can visualize that all the rotary motions are clockwise as indicated in figure 7-12.

The three-finger rule is useful for analyzing any gyroscope motion problem because if the directions of any two of the three vectors are known, the direction of the third vector can be found and the motion around this vector may be determined.

Another hand rule determines the direction of the spin vector. (See fig. 7-14.) Curve the fingers of the right hand in the direction in which the rotor is turning, as if you intended to grasp it.

The thumb will point in the direction of the spin vector. A similar rule will give you the direction of the torque vector. With the fingers of the right hand wrapped in the direction of the applied torque (the direction the gyro would rotate if the rotor were not spinning) the thumb points in the direction of the torque vector.

## DEGREES OF FREEDOM

A gyro can have two different degrees of freedom, depending upon the number of gimbals in which it is supported and the way the gimbals are arranged. Do not confuse the term "degrees of freedom" with an angular value such as degrees of a circle. The term as it is applied to gyros is an indication of the number of axes about which the rotor is free to precess.

A gyro mounted in two gimbals usually has two degrees of freedom. When two gimbals are employed it is said to be universally mounted. This arrangement provides two axes about which the rotor can precess. These two axes and the spin axis intersect at the center of gravity of the entire system (excluding the support). Thus the force of gravity does not exert a torque to cause precession. The rotor, inner gimbal, and outer gimbal are balanced about the three principal axes.

### Two Degrees-Of-Freedom Gyros

The two degrees-of-freedom gyros can be divided into two groups. In the first group the gyro's spin axis is perpendicular to the surface of the earth. Thus the gyro's rotor will spin in a horizontal plane tangent to the earth's surface. These gyros are used to establish the vertical and horizontal planes, which are the stabilized reference planes for the weapon control system.

In the second group the gyro's spin axis is either parallel to the surface of the earth or at some angle other than perpendicular. The spin axis of the gyro in the gyrocompass is maintained in a plane parallel to the surface of the earth. It is aligned in a plane of north-south meridian. Once set, it will continue to point north as long as no disturbing force causes it to precess out of the plane of the meridian.

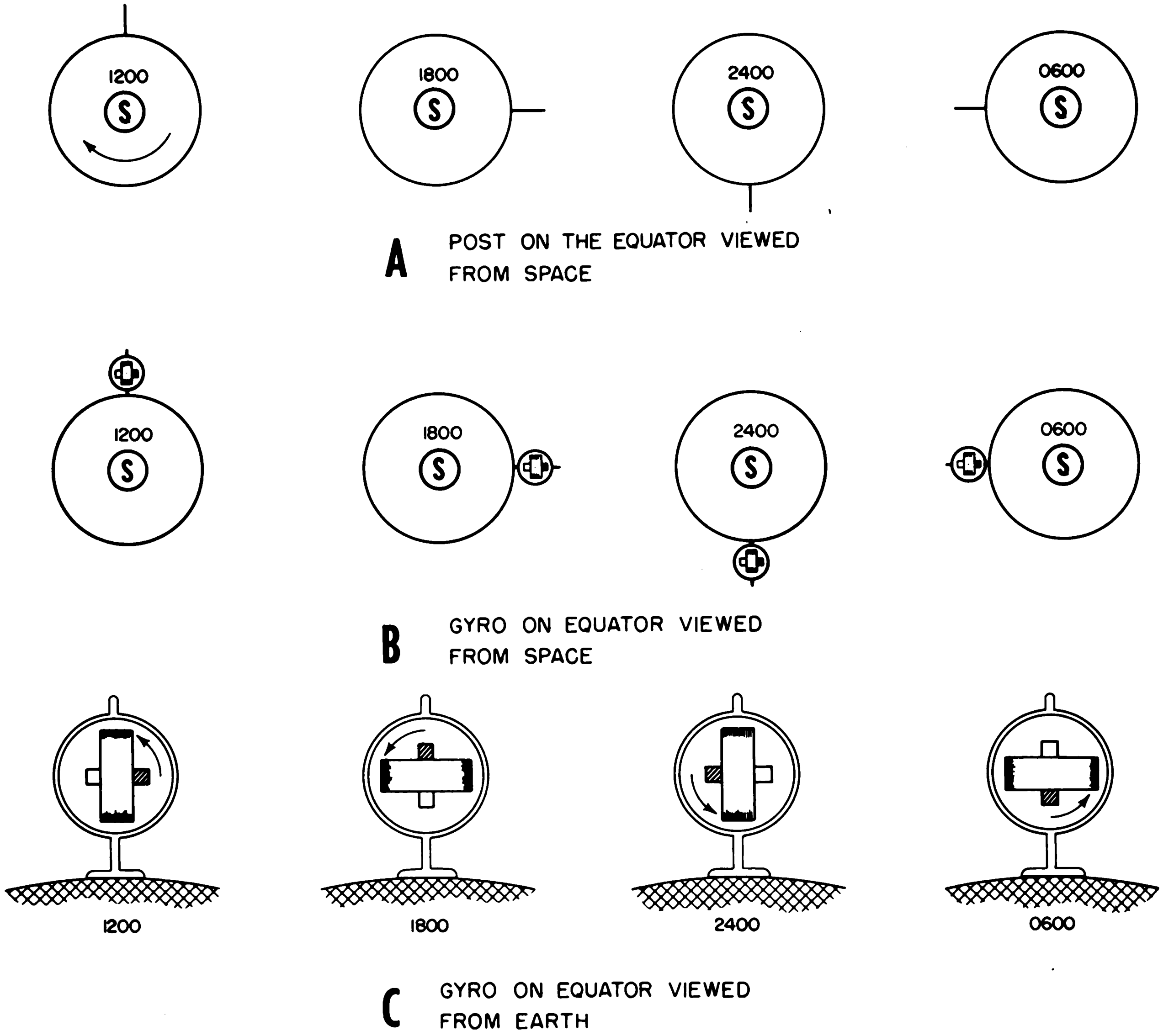
### Effect of Rotation of the Earth

A free gyro maintains its axis fixed in space, and not in relation to the earth's surface. To understand this, imagine yourself in a space ship somewhere out in space and looking at the South Pole of the earth. You could see a sphere rotating clockwise, with the South Pole in the center. Maneuver your ship until it is on a direct line with the South Pole and then cut in the automatic controls to keep it in this position. The sphere you see would make a complete rotation every 24 hours.

You could keep track of that rotation by driving a big post into the Equator as shown in figure 7-15A. If this post was upright at 1200, the earth's rotation would carry it around so that it would be horizontal and pointing to the right, or east, at 1800. Likewise, the earth's rotation would carry the post around so that at 2400 it would be upside down. Then, at 0600 the next day, the post would be horizontal and pointing left, or west. Finally at 1200 the next day the post would be back in its original position, having been carried, with the earth, through its complete rotation. Notice that the post has many positions as you observe it—because it is attached to the earth's surface and does not have rigidity in space.

If you put a gyroscope in place of the stake you would see a different action. Imagine a gyroscope mounted at the Equator with its spin axis aligned with the E/W axis of the earth. The gyro is spinning and does have rigidity in space. Look at figure 7-15B. At 1200 the spinning axis is horizontal with respect to the earth's surface. At 1800 the spinning axis is vertical with respect to the earth's surface; but the gyro is still spinning in the same plane as before, and the black end is pointing away from the earth's surface. At 2400, the spinning axis is again horizontal. At 0600 the spinning axis is again vertical, and the black end points toward the earth. Finally, at 1200 the next day, the gyro is in the same position as when it started. The plane of spin of the gyro wheel did not change direction in space while being carried through the rotation of the earth. This is because the gyro is rigid in space.

You have just imagined observing the gyro from space. Now, let's come back to earth and stand right next to the gyro. Look at the gyro in figure 7-15C. From your viewpoint on earth, the spinning axis appears to make one complete rotation in one day. As you know, the gyro is rigid and both you and the earth are rotating. The effect on a gyro of the earth's rotation is sometimes called apparent drift, apparent precession or apparent rotation.


1200
S
1800
S
2400
S
0600
S
A
POST ON THE EQUATOR VIEWED FROM SPACE
1200
S
1800
S
2400
S
0600
S
B
GYRO ON EQUATOR VIEWED FROM SPACE
1200
1800
2400
0600
C
GYRO ON EQUATOR VIEWED FROM EARTH

12.144

Figure 7-15.— Fixed direction in space.

Effect of Mechanical Drift

A directional error in a gyro is produced by random inaccuracies caused by mechanical drift and the effect of the earth's rotation (apparent drift).

We shall see later on how it is corrected for in the equipment. First, let's consider the causes of mechanical drift.

There are three general sources of mechanical drift:

1. Unbalance. A gyro often becomes dynamically unbalanced when operated at a speed or temperature other than that for which it was designed. The static balance of the gyro is upset when its center of gravity is not at the intersection of the three major axes. Some unbalance of both types will exist in any gyro since manufacturing processes cannot produce a perfectly balanced gyro.

2. Bearing friction. Friction in the gimbal earings results in loss of energy and incorrect imbal positions. Friction in the rotor bearings auses mechanical drift only if the friction is not ymmetrical. An even amount of friction all round in a rotor bearing results only in a change f the rate of rotation.

3. Inertia of gimbals. Energy is lost whenever gimbal rotates because of the inertia of the imbal. The greater the mass of the gimbal, the reater the drift from this source.

The complete elimination of mechanical drift in yros appears to be an impossibility. However, y proper design it has been kept to a minimum. ny error which still exists can be corrected or.

### eeping the Gyro Vertical

A two degree-of-freedom gyroscope with its pinning axis vertical to the earth's surface and arallel to the direction of gravity is a direction-ndicating device. Once set, it would continue to oint in the vertical as long as no disturbing orces caused it to precess from this position. iven time it will precess from the vertical. he distrubing forces caused by apparent and echanical drift are always present. To find nd maintain a vertical position, a gyro-erection ystem is necessary.

To make a gyroscope into a direction-ndicating device which indicates accurately at ll times, the following requirements must be net:

1. Torques must be provided of the correct agnitude and direction to precess the gyro in uch a manner that the spinning axis is brought o the desired direction after the rotor has been et spinning.

2. Torques must be provided to precess the yro back to the required position at the proper ate and direction so as to cancel the effects of pparent and mechanical drift.

The torques required to produce the proper recession to convert the gyro into a direction-dicating device are provided by an erecting ystem. Erection may be accomplished pneumatially, mechanically, or electrically, depending n the type of power available, and usually acts response to the force of gravity. Specific erection systems are many and varied. We will discuss some of the systems later.

## ONE DEGREE-OF-FREEDOM GYRO

A gyro enclosed in one gimbal usually has one degree of freedom, freedom of movement back and forth at a right angle to the spin axis. You should know something about the application of gyros in a guided missile, so let's put one of these one-degree-of-freedom gyros in a missile and observe its operation. We will mount it so that its axis of spin is parallel to the axis of travel of the missile. It is mounted now much like the flywheel in an automobile. It is spinning, and we have mounted it so that it can swing right to left. We can say that it has one degree of freedom. If the missile should nose up or down, the gyro would be forced to move exactly as the missile does in these directions. However, if the missile should turn left or right, the gyro would not change its attitude since it has freedom of motion in these directions. The spin axis would be fixed in the original direction of missile flight.

### Rate Gyros

Rate gyros are used in the fire control and missile fields to detect and measure the angular rate of change of position of an object.

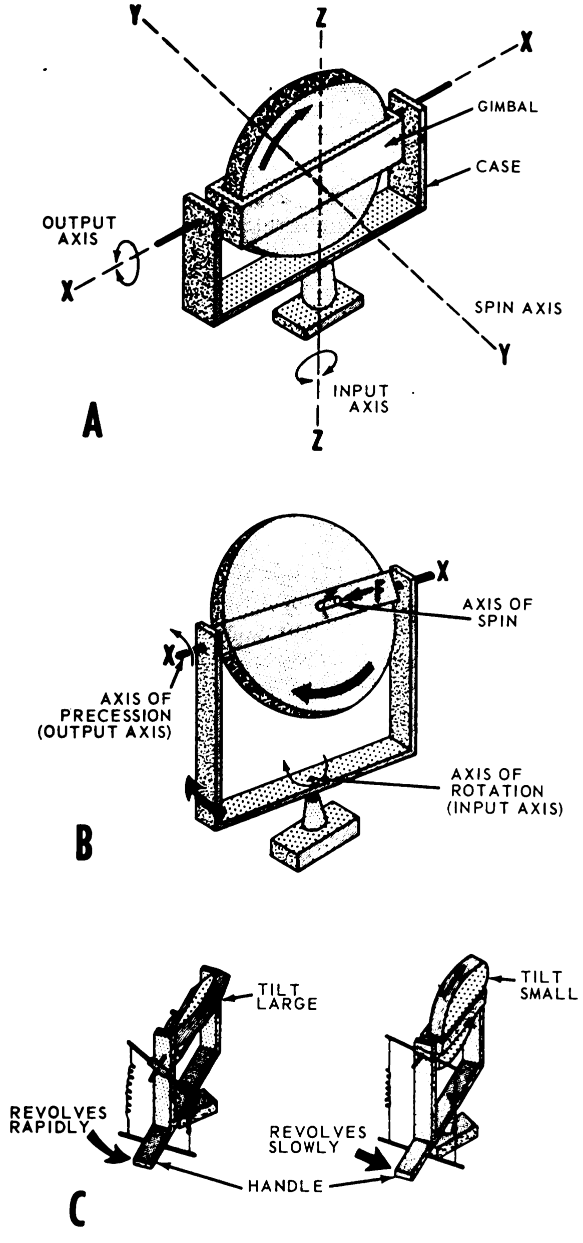
Rate gyros found in missile equipment may be called by different names, depending on which OP or other reference you are reading. Nevertheless, no matter what name is applied to a gyro which measures rate of change it can be called a rate gyro.

Like the free gyro, the rate instrument contains a mechanical system consisting of the spinning rotor and associated gimbal system. It differs in that it has one gimbal, so that one degree of freedom is obtained. Further, the rotor is restrained by some means, usually a spring, when it is precessed.

### Rate-of-Turn Gyro

A rate-of-turn gyro is nothing more than a simple gyroscope which is installed to take advantage of the principle of precession. It is important to remember that, among other factors, the rate of precession of a gyro is proportional to the force attempting to precess the unit.

Look at the gyro installation in figure 7-16. This gyro has one degree of freedom. Movement about the Z-Z axis (input axis) is controlled by positioning the case with an attached handle.



A. RATE-OF-TURN GYRO MOUNTING
B. RATE-OF-TURN GYRO PRECESSES
C. AMOUNT OF PRECESSION IS PROPORTIONAL TO THE RATE-OF-TURN

12.152

Figure 7-16.—Rate of turn gyro.

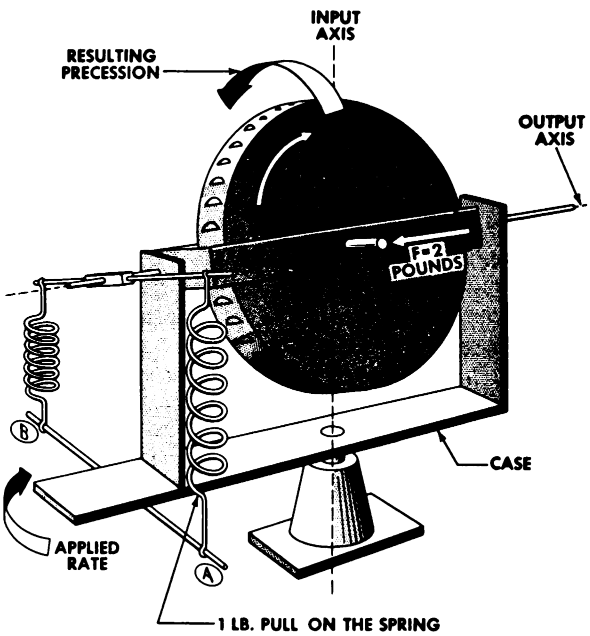
If you attempt to change the plane of rotation of the gyro by rotating the case about the Z-Z axis, the gyro will precess as shown in figure 7-16B. From what you have learned earlier in this chapter, the gyro does not appear to be obeying the rules for precession. However, turning the gyro case has the same effect as applying a torque on the spin axis parallel to the X-X axis. This is illustrated by arrow F in figure 7-16B. The direction of precession may be determined by using the right hand rule discussed earlier.

The torque applied at F will cause the gyro to precess at right angles to the torque. Likewise, attempting to turn the gyro case will cause the same result. The gyro will precess as shown by the arrows, around the X-X axis (output axis).

Since the rate of precession is proportional to the applied force, you can increase the rate of precession by increasing the speed with which you are moving the handle (fig. 7-16C). In other words you have a rate-of-turn gyro. The faster you turn the handle, the more the gyro will precess, for the amount of precession is proportional to the rate at which you are turning the gyro case.

This characteristic of a gyro, when properly utilized, fits the requirements needed to sense the rate of motion about the missile's roll, pitch, and yaw axes.

Figure 17-17 shows a method of restraining the precession of a gyro to permit the calculation



12.153

Figure 7-17.—Precession of a spring restrained rate of turn (rate) gyro.

of an angle. A pair of springs have been attached to the crossarm of the output shaft. These springs serve to restrain the free precession of the gyro. The gyro may use other types of restraint, but no matter what type of restraint is utilized, the gyro is in effect harnessed to produce some useful work.

As a gyro precesses, it exerts a certain force which is proportional to the momentum of the spinning wheel and the applied force. For example, suppose you rotate the gyro case (fig. 7-17) at a speed corresponding to a horizontal force of 2 pounds at F. Obviously, the gyro will precess; and as it does, it will cause the crossarm to pull up on spring A with a certain force, say 1 pound. (This amount of force would vary with the length of the crossarm.)

If you continue to turn the gyro case at this rate, the precession of the gyro will continually exert a pull on the spring. More precisely, the gyro will precess until the 1 pound pull of the crossarm is exactly counterbalanced by the tension of the spring, it will remain in a fixed position as shown in figure 7-17. That is, it will remain in the precessed position as long as you continue to rotate the gyro case at the same, constant speed.

When you stop moving the handle, it is equivalent to removing the force at F, and the gyro stops precessing. The spring is still exerting a pull, however, so it pulls the crossarm back to the horizontal.

Suppose you now rotate the gyro case at a speed twice as fast as before, and in the same direction. This will be equal to a 4 pound force applied at F and a resulting 2 pound pull by the crossarm on spring A. In this situation the gyro will precess twice as far before the tension on the restraining spring equals the pull on the crossarm.

Another type of rate gyro widely used in missile equipment is the floated gyro unit. This unit generally uses a restraint known as a torsion bar. The advantage of the torsion bar over the linear spring is that the torsion bar needs no lever arm to exert torque. The torsion bar is mounted along the output axis (fig. 7-18), and produces restraining torque in either direction by twisting instead of pulling. Also there is no gimbal bearing friction to cause interference with gyro operation.

The viscous fluid surrounding the rotor serves to provide protection from shock and performs the function of damping the oscillations resulting from sudden changes in the angular rate input. In this gyro the inner gimbal displacement must be measured with some type of electrical pickoff. As the gyro case is rotated about the input axis, clockwise or counterclockwise, a precession torque will be developed about the output axis that will cause the inner gimbal to exert torque against the torsion bars. The torsion bars provide a restraining torque proportional to the amount of the inner gimbal's displacement. When the exerted gimbal torque is exactly opposed by the restraining torque provided by the torsion bars, the inner gimbal displacement will be proportional to the rate of rotation of the gyro case about the input axis. The pickoff measures this displacement and provides a signal whose amplitude and polarity (or phase) represent the direction and magnitude of the input angular velocity.

The important point to remember is that the "rate" gyro measures the RATE OF ROTATION ABOUT ITS INPUT AXIS.

### Rate Integrating Gyro

Another floated gyro that is widely used in missile control equipment is the rate integrating gyro. This unit, also called the Draper gyro and the hermetically sealed integrating gyro, to list a few of its more common names, is a viscous damped, single-degree-of-freedom gyro with a torque generator and a signal generator mounted on its output shaft. Figure 7-19 shows a cutaway view of the unit. The principal components of the

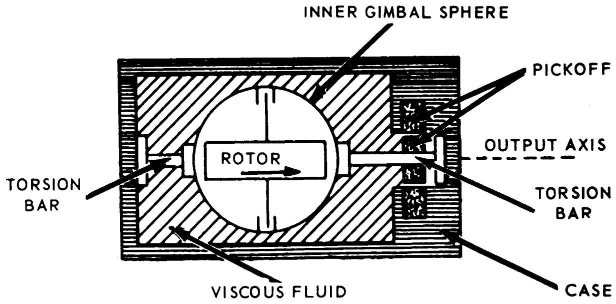


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Figure 7-18.—Torsion bar-restrained floated rate gyro.

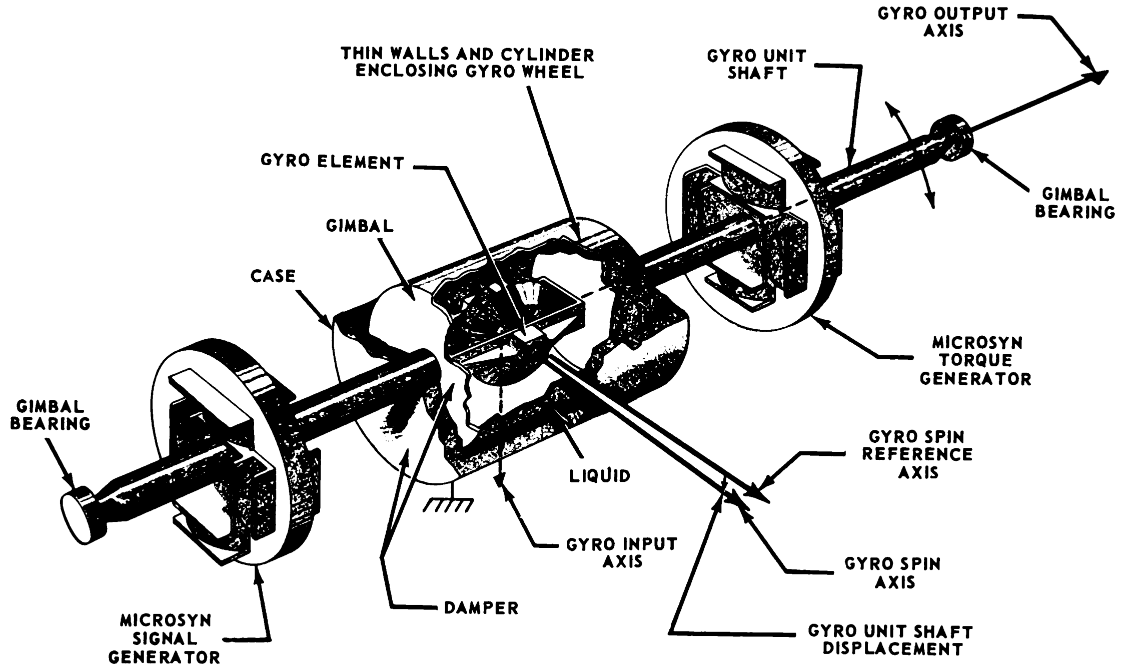

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Figure 7-19.—Floated gyro unit.

gyro are the gyro rotor, gimbal, signal generator, torque generator, and the viscous damping fluid. The gyro rotor and stator are in a sealed cylinder filled with a gas, usually helium. The gas serves to transfer heat generated by the gyro stator windings to the surface of the cylinder. The closed metal cylinder acts as the inner gimbal and is mounted on precision bearings. The space between the gimbal and case is filled with a viscous fluid of high specific gravity. Because of the high specific gravity of the fluid, it serves to float the inner gimbal and its shaft. This reduces the gimbal bearing friction. In this way mechanical drift due to friction is greatly reduced.

The pickoff is a microsyn signal generator whose rotor is attached to one end of the inner gimbal shaft. The electrical output of the signal generator is proportional to the angular displacement between the inner gimbal and the case. The torque generator, also a microsyn whose rotor is attached to the other end of the gimbal shaft, provides a means of applying command signals to the gyro. Microsyns were covered in chapter 4.

The "rate integrating" gyro is a gyroscope which measures the AMOUNT OF ROTATION about its input axis. This unit's precessional angle is proportional to the angular displacement about its input axis.

An example of a working rate integrating gyro is shown in figure 7-20. You will observe that the rotor is mounted within a light metal sphere which serves as the inner gimbal (1) and that this sphere is floated in a viscous fluid (2) inside the cylindrical case. High quality bearings are incorporated in this gyro to allow a near frictionless movement of the inner gimbal about the output axis. A pickoff (3) is attached to the inner gimbal and the case to measure the displacement of the inner gimbal with respect to the case. The pickoff provides a signal whose amplitude and polarity (or phase) indicate the direction and amount of precession.

A torquer motor (4) on the opposite end of the inner gimbal axis, is supplied with signals that apply various amounts of torque to the inner gimbal sphere. These varying amounts of torque are used to compensate for gyro drift, unwanted input rotation (earth's rotation), and other undesired quantities.

The rate integrating gyro is sometimes used in inertial navigation to stabilize a platform upon which are mounted the components of the system,

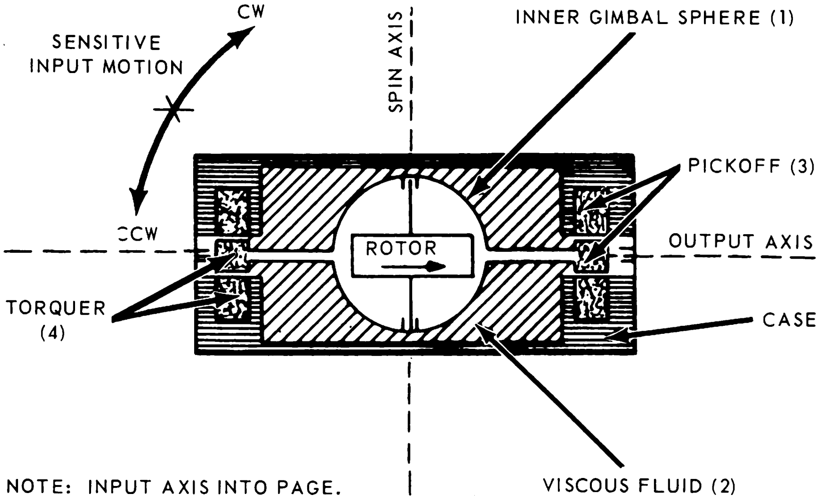

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Figure 7-20.—Working example of the rate integrating gyro.

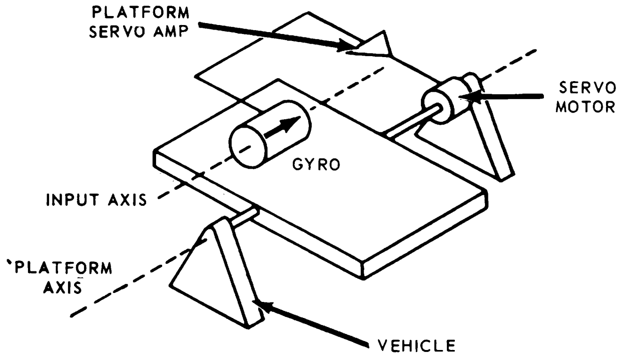

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Figure 7-21.—Simple platform stabilizing system.

an example of which is shown in figure 7-21. Stabilization is accomplished by installing the gyro on a platform in such a manner that the input axis of the gyro is parallel to the axis of rotation of the platform. Any motion of the vehicle (in which the navigation system is installed) that tends to rotate the platform about its axis will be sensed by the gyro and the gyro will precess about its output axis. The gyro pickoff will send a signal to the platform's servoamplifier which will result in an amplifier output that will rotate the servomotor, driving the platform (relative to the vehicle) in a direction opposite to the direction of vehicle rotation. The platform will be driven until the gyro pickoff signal is zero.

The platform, therefore, moves with respect to the vehicle, but remains stationary with respect to the reference plane of direction. In the example shown, the platform will remain horizontal regardless of vehicle motion about the platform axis.

The rate integrating gyros used in the FBM weapon systems are called the Inertial Reference Integrating Gyro, the Reduced Excitation Inertial Reference Integrating Gyro which is smaller and more accurate, and the Miniature Integrating Gyro. The principles of operation of these gyros are identical with the basic integrating gyro we just described.

## STABLE PLATFORM

It was brought out previously that an inertially guided missile required complete knowledge of a prescribed theoretical flight path to the target and the internal means of measuring the characteristics of its actual flight path. In order to correlate the prescribed missile flight characteristics with those of its actual flight, common units of measure and a common coordinate system (reference frame) are required. The common unit of measure is velocity measured along the axes of the coordinate system.

In this way, predetermined velocities can be compared with actual missile flight performance. Our first concern here is to establish a coordinate system common to the weapon system aboard ship and to the missile that will be valid both while the missile is in the tube before launch and during its flight after launch. Thus a nonrotating coordinate system, isolated from both ship and missile angular motions, is needed. An inertial coordinate system established by gyros will meet these requirements.

An element called the stable platform that is fully stablized about the three axes of the coordinate system is the heart of the inertial guidance system. A stable platform is established in the Ship Inertial Navigation System (SINS) and in the missile. The SINS stable platform is aligned so that its axes are parallel to the north-south axis, the east-west axis, and the local vertical. The missile stable platform axes are aligned to the launch bearing, the local horizontal and the local vertical. The point of origin for both coordinate systems is located at the point of intersection of parallel planes, namely the local vertical and local horizontal planes.

## Gimbal System

The gimbal system contains three interconnected gimbals: outer, middle, and inner (fig. 7-22). A case not shown in the illustration encloses the gimbal system. The outer gimbal is attached to the case hence to the ship or missile frame, so that it has a single degree of freedom with respect to the case. The middle gimbal is attached to the outer gimbal so that it has a single degree of freedom with respect to the outer gimbal. The inner gimbal is attached to the middle gimbal so that it has a single

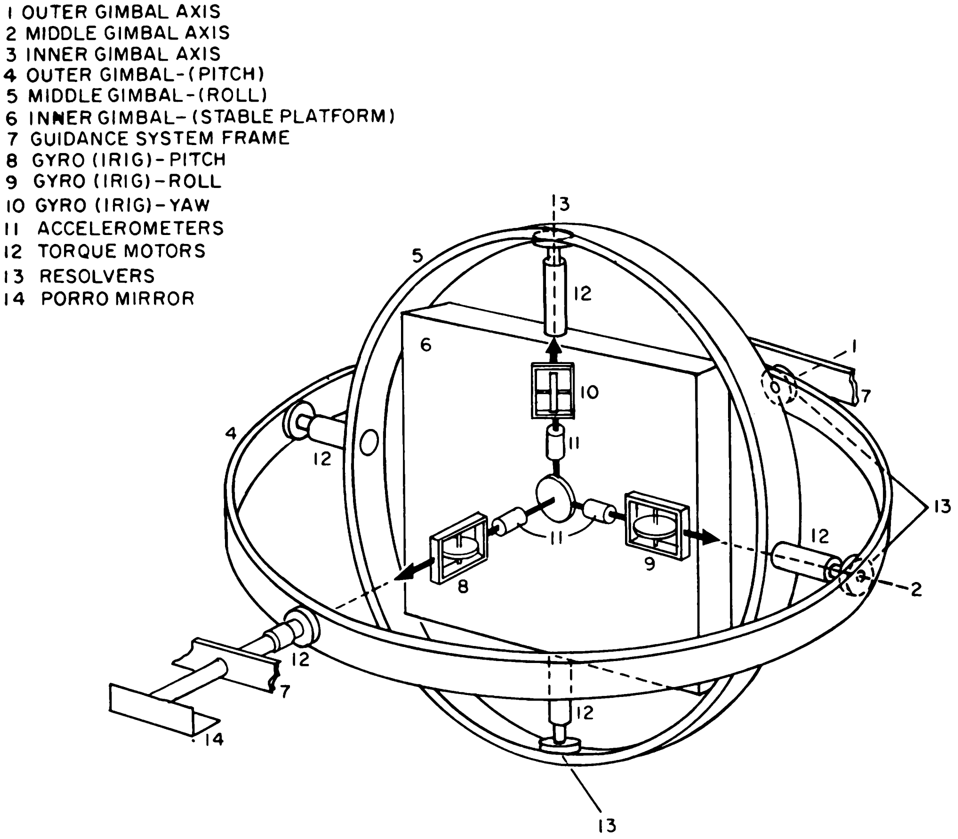

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Figure 7-22.—Stable platform configuration.

degree of freedom with respect to the middle gimbal. The gimbal axes are 90 degrees apart from each other. Thus the inner gimbal is fully stabilized and is referred to as the stable platform. Since the stable platform has three degrees of freedom, it is isolated from any angular motion of the case.

Gyro System

Three Inertial Reference Integrating Gyros (IRIG) are mounted on the stable platform with their respective input axes mutually perpendicular. The IRIG's sense torques applied to the stable platform about the gimbal axes. The IRIG outputs are applied through a servosystem to the gimbal servomotor mounted on the gimbal axes. The motors apply counter torques to the gimbals about which the torques were initially sensed. The counter torques are applied until the IRIG outputs are nulled. In other words, angular motions of the case cause the motors to drive their respective gimbal so as to maintain the initial attitude of the stable platform with respect to the case. Therefore, angular displacements of the gimbals are a measure of the case (ship or missile) attitude with respect to the inertial coordinate system established by the stable platform. Gimbal displacement signals are generated for use in the missile guidance system.

For reasons that will become apparent when we discuss the FBM problem the axes of the missile inertial coordinate system are rotated out of alignment with the SINS coordinate system. But our explanation of the stable platform operation is not affected by this rotation.

The stable platform provides us with a stabilized coordinate system within which motions can be measured. In the process of maintaining this coordinate system, angular motions are measured by the IRIGs. Since an IRIG is not affected by the linear motion of the ship or missile another type of inertial device, called an accelerometer, is used to determine linear motions.

## ACCELEROMETERS

An accelerometer may be defined as a device which gives an indication, usually in the form of a voltage, proportional to the acceleration to which it is subjected. The operation of an accelerometer is based on the property of inertia (Newton's first law of motion). A simple demonstration of inertia happens to us almost every day. You know that if your automobile is subjected to acceleration in a forward direction, you are forced back in the seat. If your auto comes to a sudden stop, you are thrown forward. When your auto goes into a turn, you tend to be forced away from the direction of the turn—that is, if your auto turns left, you are forced to the right, and vice versa.

If we replace the human in an auto with a mass suspended in an elastic mounting system, any acceleration of the auto will cause movement of the mass relative to the auto. The amount of displacement is proportional to the force causing the acceleration. The direction in which the mass moves in relation to the auto is opposite to the direction of the acceleration.

The movement of the mass is in accordance with Newton's second law of motion which states that when a body is acted on by force, its resulting acceleration is directly proportional to the force and inversely proportional to the mass of the body.

When no acceleration is present, the mass will be at rest. When acceleration is present, the mass will lag in proportion to the acceleration force. In other words, the car moves but the mass wants to remain at rest. Now that we have discussed the basic physical principles involved, let's take a close look at a simple accelerometer.

### THE BASIC ACCELEROMETER

Figure 7-23 is a simplified drawing of a basic accelerometer. It consists of a mass, called the inertial mass or seismic mass, which is free to slide along the sensitive axis within the case. The movement of the mass is limited by the springs. When the case is accelerated, the seismic mass, because of its inertia, tends to remain stationary. This results in a relative movement of the mass with respect to the case. When the stretch of the springs overcomes the inertia of the mass, the springs cause the mass to stop moving with respect to the case. The displacement of the mass with respect to the case is directly proportional to the acceleration of the case. When the case stops accelerating, the springs return the mass to its zero position (the reference position). To keep the springs from

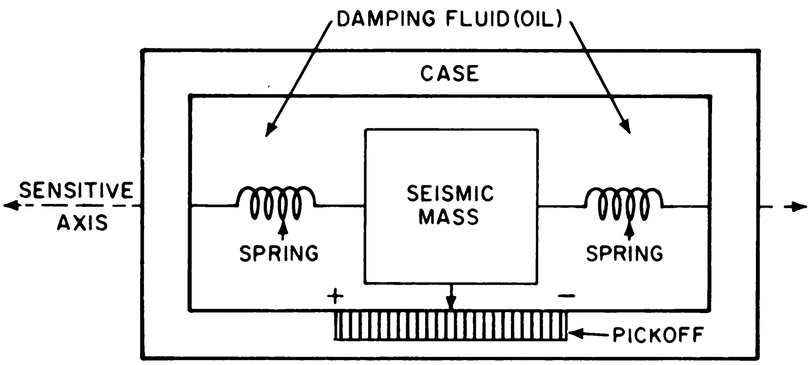

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Figure 7-23.—The basic accelerometer.

causing the mass to overshoot and oscillate about the reference position, some form of damping is needed. This is usually supplied by using an oil-filled case with vanes for oil to bypass the mass.

An accelerometer is sensitive to gravity when its sensing axis is positioned so that gravity can move or attempt to move the seismic mass. This is useful in that we can use gravity as a reference for testing purposes, but it can be a serious problem because of the errors it may cause in acceleration measurements. If the unit is placed with the sensing axis vertical, the mass will be displaced such that the output is one G, or one gravity. This is done during testing, then when the sensitive axis is turned so that it is horizontal to the earth, the springs center the mass, and the output of the unit is zero.

## PENDULOUS INTEGRATING GYRO ACCELEROMETER (PIGA)

The PIGA is a type of accelerometer used in the missile field. It can be used in either an inertial guidance or navigation system. This unit uses the principles of the two-degree-of-freedom gyro, previously discussed, combined with Newton's second law of motion.

Basically, the device consists of a spinning rotor, inner gimbal, outer gimbal, housing, and a pendulous mass which is attached to the rotor spin axis. A simplified diagram of the PIGA is shown in figure 7-24. If the unit is accelerated along the pivot axis of the outer gimbal (At) the pendulous mass will have a tendency to lag behind, because of inertia, and a resulting force will be applied to the inner gimbal at a distance (r) from the pivot axis. This force will exert a torque about the inner gimbal axis, proportional to the magnitude of the acceleration, which will cause the gyro to precess about its outer gimbal axis.

From the previous discussion relating to gyro precession, we know that the gyro precession rate is directly proportional to the applied torque. Since, in this situation, the applied torque is a function of and is directly proportional to the sensed acceleration, the precession rate of the gyro is also proportional to the sensed acceleration.

When the unit is used as an accelerometer, a pickoff attached to the outer gimbal axis is used to measure the RATE OF ROTATION of the gimbal about its axis. If velocity, with respect to some starting point, is the desired output, a pickoff is used to measure the AMOUNT of outer gimbal rotation.

Any accelerometer must be sensitive to accelerations along, and not perpendicular to, its sensitive axis. An axis parallel to the outer gimbal axis is the sensitive axis of the PIGA. Any acceleration in such a direction (Af in fig. 7-24) that it causes a reaction torque to exist on the pendulous mass in a direction perpendicular to the accelerometer's sensitive axis will cause the inner gimbal to precess about its pivot axis. If this reaction force persists, the plane of the inner gimbal will become coincident with the plane of the outer gimbal (gimbal lock), the gyro will tumble, and the acceleration sensing action will be lost. To prevent this situation from occurring, a torque of the correct magnitude and direction is applied about the outer gimbal axis. This torque is applied by the torquer

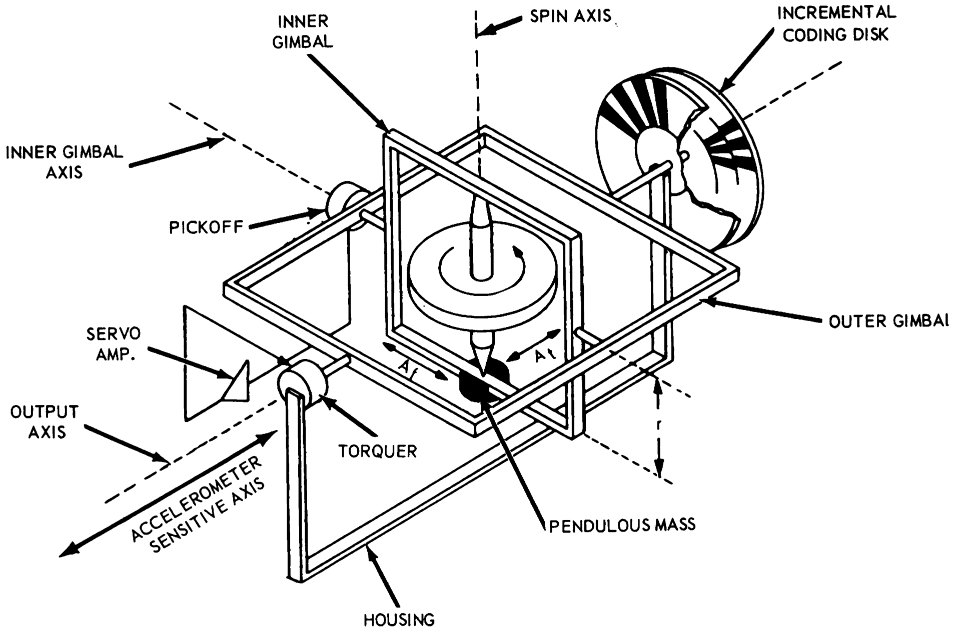

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Figure 7-24.—PIGA simplified diagram.

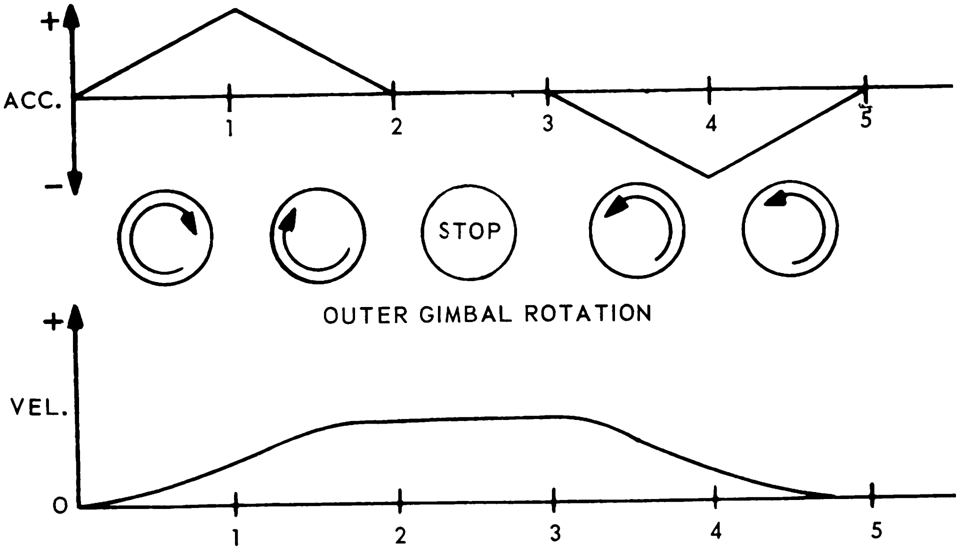

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Figure 7-25.—Sensed acceleration and vehicle velocity graph.

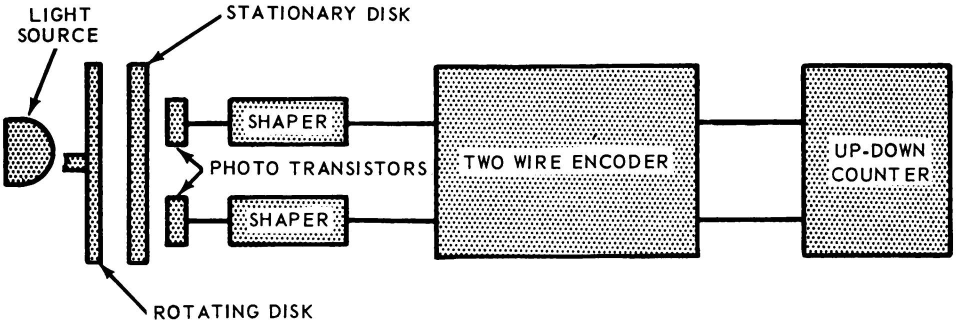

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Figure 7-26.—Functional diagram of velocity indicating circuits.

located on the outer gimbal axis. (See fig. 7-24.) The torquer receives its power from the servo-amplifier which is controlled by a signal from the pickoff located at the intersection of the inner and outer gimbal axes. When the planes of the two gimbals are perpendicular, the pickoff's output is zero (nulled). As soon as the inner gimbal attempts to precess, due to any acceleration perpendicular to the accelerometer's sensitive axis, the pickoff will supply a signal to the high gain servoamplifier. This causes a torque to be applied to the outer gimbal axis, thus cancelling the inner gimbal precession.

### Acceleration Measurement

Since a velocity measurement (precession rate) is readily obtainable from the PIGA, the process of integration must have been performed within the instrument. The direction of the outer gimbal rotation is dependent on the direction of the applied torque and, therefore, the direction of the sensed acceleration.

A graph of the sensed acceleration and the vehicle velocity attained due to this acceleration is shown in figure 7-25. From time 0 to 1, the acceleration is increasing; the outer gimbal rotation is also increasing and is maximum at time 1, the point at which the acceleration is maximum. Between times 1 and 2, the outer gimbal's rate of rotation is decreasing. However, the gimbal is still rotating in the same direction as in time 0 to 1. From time 2 to 3, the vehicle acceleration is zero and the outer gimbal has stopped rotating. The total number of degrees rotation of the outer gimbal, having reached its highest value, indicates that the vehicle is now moving at a constant velocity (no acceleration).

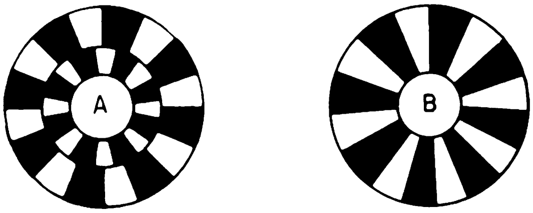

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Figure 7-27.—Incremental coder discs.

Between times 3 and 5, the acceleration is in the opposite direction (deceleration) from that present during time 0 to 2, and therefore, the gimbal rotates in the opposite direction. This indicates a deceleration of the vehicle, and the net number of degrees of gimbal rotation clockwise (CW) is decreasing. At time 5, the total number of degrees of counterclockwise (CCW) rotation is equal to the total number of CW degrees of rotation. The net rotation is therefore zero, indicating that the vehicle velocity is now zero.

In order to determine the vehicle's instantaneous velocity, some method of indicating the net number of degrees of rotation of the outer gimbal must be utilized. A block diagram of the circuitry commonly used to perform this function is shown in figure 7-26. The illustration also indicates the basic process used to accomplish the indication. The incremental coder contains one stationary and one rotating disk, with alternating transparent and opaque sections (fig. 7-27), which provide a means of measuring the amount and direction of outer gimbal rotation. Disk "A" is fixed to the PIGA case and disk "B" is attached to the movable output shaft. A light source is mounted on one side of the disks and two photoelectric cells on the other side. When gimbal rotation occurs, the transparent and opaque sections of the two disks change the amounts of light reaching the photo cells. When the opaque portions of the disks block the light from reaching a cell, the output from the cell is zero. If the disks are positioned so that the light is allowed to pass through to a cell, the cell's output will be proportional to the amount of light that strikes it. This will result in a series of pulses being applied to the shaping circuits during gimbal rotation. The output of the shapers is encoded by the two-wire encoder and fed into a counting circuit.

Disk rotation of approximately 1/2048 revolution will cause a pulse to appear at the output of the two-wire encoder, and each output pulse represents approximately a .3 ft/sec change of vehicle velocity.

In a velocity meter such as the PIGA, the vehicle acceleration is proportional to the rate of rotation of the output shaft, and the vehicle velocity is proportional to the total amount of the output shaft rotation. The direction of the output shaft rotation indicates the direction of the vehicle's acceleration and adds to, or subtracts from, the shaft's position or previous velocity.

Therefore, since the gimbal output shaft total rotation is proportional to the vehicle's instantaneous velocity, we have utilized devices which give digital pulse outputs for any incremental change of the output shaft's position in either the positive or negative direction (CW or CCW). The algebraic sum of the output pulses represents the vehicle's current velocity.

The outputs of the photo cells are sent to the shaping circuits, which are bistable circuits whose operating status depends on the amplitude of the signals they receive. The outputs of the shaper circuits are fed into the two-wire encoder, which furnishes a digital pulse output on two wires. One wire represents gimbal rotation in the positive (CW) direction, and the other represents gimbal rotation in the negative (CCW) direction.

### PULSE INTEGRATING PENDULOUS ACCELEROMETER (PIPA)

The pulse integrating pendulous accelerometer (PIPA) is utilized in certain FBM guidance

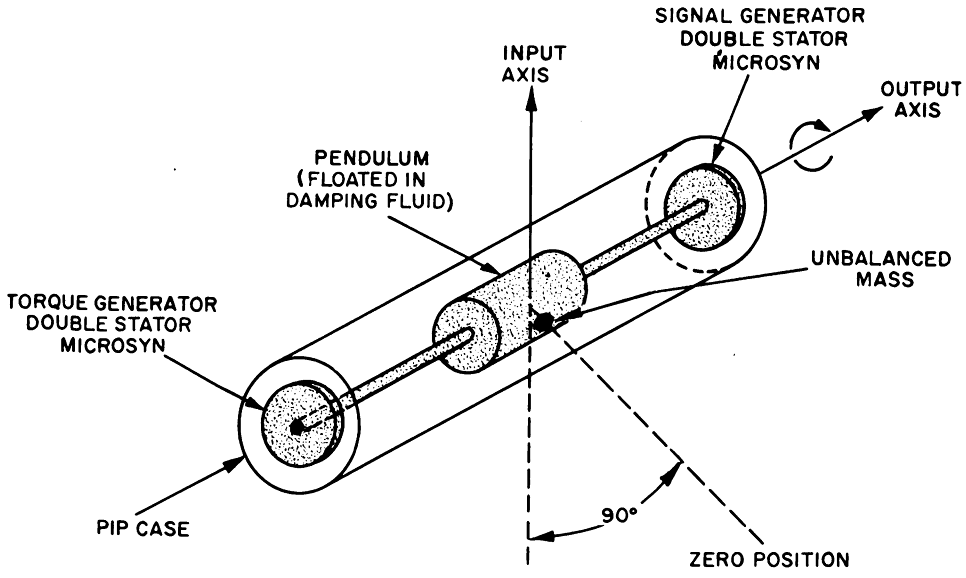
SIGNAL GENERATOR DOUBLE STATOR MICROSYN
INPUT AXIS
OUTPUT AXIS
PENDULUM (FLOATED IN DAMPING FLUID)
UNBALANCED MASS
TORQUE GENERATOR DOUBLE STATOR MICROSYN
PIP CASE
90°
ZERO POSITION

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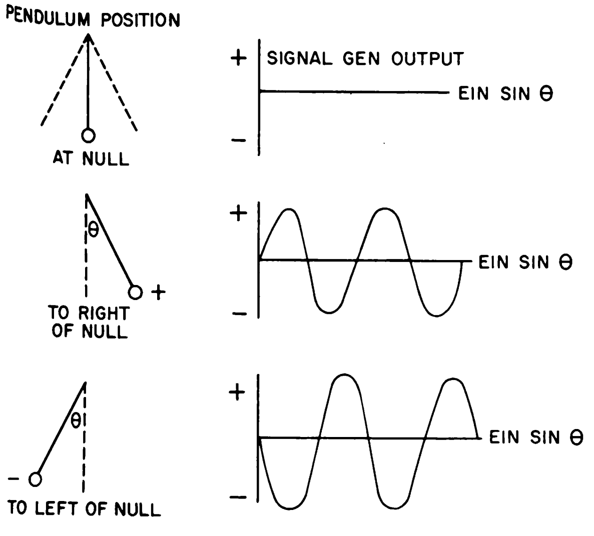
Figure 7-28.— PIPA functional diagram.



71.21
Figure 7-29.—Relationship of signal generator output for pendulous positions.

systems to measure the missile's acceleration. A functional diagram of this unit is shown in figure 7-28. Basically, the unit consists of a metal cylinder enclosing a smaller metal cylinder which contains a magnetically suspended mass (pendulum) floating in damping fluid, and two microsyns, one which serves as a torque generator and the other as a signal generator. The two microsyns are of the double stator type (Ducosyn), and provide magnetic suspension for the pendulum cylinder. The two microsyns are located on the output axis of the pendulum cylinder.

The function of the signal generator is to monitor the instantaneous deflection angle of the pendulum. It is utilized in such a manner that the amplitude of its output is proportional to the amount by which the pendulum is deflected, and the phase of this output signal indicates whether the pendulum is to the right or left (positive or negative) from the null position (fig. 7-29). The operation of this unit may be compared to that of the resolver discussed in a previous chapter, its primary being excited by an AC signal and the secondary (output) signal being equal to the input voltage times the sine of the pendulum's deflection angle. The phase of the signal generator's AC input voltage is used to determine the length of time the pendulum is deflected from the null position, and the polarity of the torquing signal applied to the torque generator thus controlling the direction in which torque is exerted on the pendulum. The measured acceleration is determined by the ratio of the positive deflection time (T1) to the negative deflection time (T2), as shown in figure 7-30.

In practice, the pendulum is caused to oscillate about the null position at its natural frequency; thus, with zero vehicle acceleration, T1 is equal to T2, resulting in a measured acceleration value of zero.

Illustrated in figure 7-31 are the pendulum deflection angles, part A showing a positive deflection and part B showing a negative deflection. NOTE THAT THE POSITIVE OR NEGATIVE DEFLECTION ANGLE IS DETERMINED BY THE POSITION OF THE PENDULUM (RIGHT OR LEFT) WITH RESPECT TO THE NULL POSITION. Acceleration causes an inertial force (F) to be felt by the unbalanced mass of the pendulum, whether it is deflected to the right or left of the null position. This force, acting about the pendulum pivot axis (which is the output axis shown in fig. 7-28), generates a pendulous torque (P). The amount of P is proportional to the linear acceleration felt by the pendulum. The other torque (M) is exerted on the pendulum by the torque generator located on the PIPA output axis. Torque (M) is of a constant magnitude, and for this discussion it will be assumed that M exceeds P at all times (as shown by the length of the torque arrows in fig. 7-31).

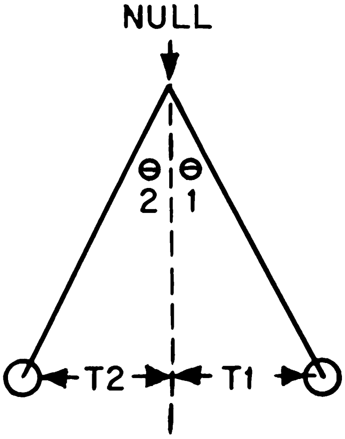


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Figure 7-30.— Pendulous deflection times at zero acceleration.

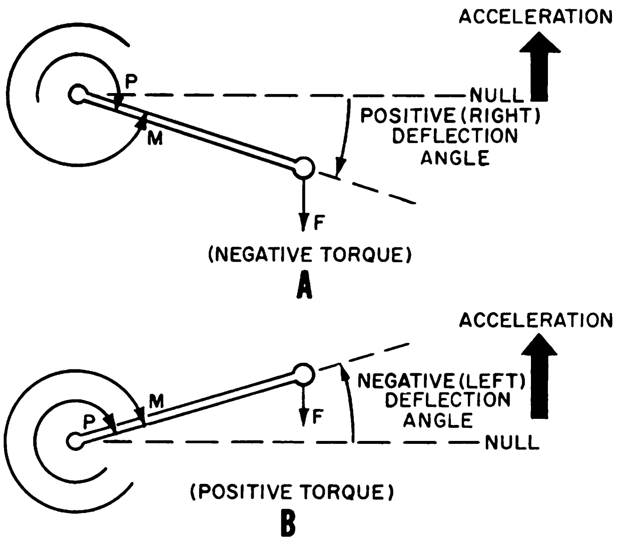

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Figure 7-31.—PIP (pendulum) deflection angles.

The signal generator (fig. 7-28) monitors the pendulum deflection angle and issues a signal that will control the direction in which torque M is applied to ensure that the pendulum is always driven towards a zero deflection angle. However, since the direction of torque M will not change until the pendulum has passed through its zero position (null), an oscillatory motion will result. The pendulum deflection is sufficiently small so that this sinusoidal variation of torque P does not, in practice, change its proportional relationship to the acceleration.

Operation of the PIPA during the time the torque generator is applying a negative torque to the pendulum is shown in figure 7-31, part A. In this situation, M and P are in opposite directions, and since M is larger than P, the pendulum is driven towards the null position. When the pendulum has passed through the null position the signal generator will change the direction of M and a positive torque (fig. 7-31, part B) will again drive the pendulum towards the null position. After the pendulum has again crossed the null position, M will be applied as a negative torque. If the vehicle is experiencing no acceleration, there is no torque P, and the pendulum, influenced only by the constant magnitude torque M, operates for equal time intervals on the right and left sides of the null position. However, if the vehicle is experiencing an acceleration as shown, torque P is not zero, and the M plus P net torque, which returns the pendulum to null, is of different values (magnitudes) during the positive and negative deflection angles. The larger restoring torque that exists when M and P act in the same direction returns the pendulum to the null position more quickly than the smaller restoring torque that is present when M and P oppose one another. Hence, the positive and negative torques are applied to the pendulum for unequal time intervals when the PIPA senses any change in the vehicle acceleration.

At this point you should have a thorough understanding of inertial devices. In subsequent chapters of this training manual we will discuss the application of inertial devices to the Polaris Guidance System and to the overall FBM Weapon System operation.

CHAPTERS 8, 9, AND 10 (PAGES 128 THROUGH 220) HAVE BEEN DELETED FROM THIS EDITION.

# CHAPTER 11

# POSEIDON MISSILE LAUNCHING SYSTEM AND OPTICAL ALIGNMENT GROUP

This chapter continues the discussion of the shipboard FC problem. The FCS computes the guidance data, generates the control signals, and transmits this information to the missile via the missile launching system. We will describe the operation of the launching system as it relates to the FCS so that you will be able to follow the sequence of events up to and including the missile away signal. In addition, this chapter includes a description of the Alignment Group which measures the azimuth (bearing) misalignment angle of the missile guidance system. The majority of this equipment is located in the missile compartment and is the responsibility of the FTB. We will define the misalignment angle and relate it to the missile alignment computations. Then, we will describe the method used to measure the angle so that you will be able to associate the alignment group with the rest of the FC equipment.

## MISSILE LAUNCHING SYSTEM

The Missile Technicians are responsible for the maintenance of the missile launching system (MLS). We are interested in the interface between the MLS and the FCS. Control of the MLS and some associated ship system equipment is performed locally or remotely. When under local control, (during loading, cruising, training, and missile jettisoning), all operations are manually initiated at the launcher control panel. When under remote control, (during a missile launch, tactical mode), the launcher control panel automatically initiates various operations upon receipt of commands from FC. The MLS accomplishes the ordered task and reports its status to FC. Therefore, a functional description of the MLS sequence of operation in the tactical mode is included in this manual.

The MLS provides for missile stowage, protection, and ejection. The 16 missiles are individually stowed and protected for extended patrol periods. The missiles are ejected, on command, while the submarine is surfaced or submerged. Missile ejection is accomplished by the application of a high-pressure gas mixture to the base of the missile. The missile is launched by a controlled buildup of pressure beneath the missile, causing it to rise smoothly out of the launcher tube. This results in a flameless missile launch with first-stage rocket motor ignition occurring a safe height above the submarine.

## MK 24 LAUNCHING SYSTEM (POSEIDON)

The Mk 24 launching system is installed onboard some 616, 627, and 640 class FBM submarines in support of the POSEIDON missile. The launching system stows, protects, and is capable of launching 16 POSEIDON missiles during a surface or submerged launch. Each missile is resiliently mounted in the launcher tube to prevent shock and vibration damage. Missile tube functions during prelaunch, launch, and postlaunch operations are controlled and monitored by the launching system. Fail-safe devices prevent inadvertent launching of the missiles. Missile launch is accomplished by controlled release of a mixture of gas, steam, and water into the eject chamber beneath the missile. As previously stated, this results in a flameless missile launch, with first-stage rocket motor ignition occurring at a safe height above the submarine.

The Mk 24 launching system, located in the missile compartment consists of Missile Launcher Tube Mk 12 Mod 0, Missile Support Group Mk 2 Mod 0, Umbilical Retractors Mk 1 and Mk 2, Missile Launcher Control Group Mk 18 Mod 2, and Missile Ejector Group Mk 8 Mod 0. Figures 11-1, 11-2, and 11-3 illustrate the components of the Mk 24 launching system and their location.

### Missile Launcher Tube Mk 12 Mod 0

The missile launcher tube provides storage and servicing facilities for the missile during patrol and missile support during launch. Each launcher tube is installed within an outer tube. Watertight access doors in the outer tube open to penetrations in the launcher tube to provide access to the missile. Passages between the launcher and outer tubes are sealed by interface seals, and the space between the two tubes is filled by a polyurethane foam (grouting) filler. The major components of each missile launcher tube are a launcher tube assembly and a launcher tube closure.

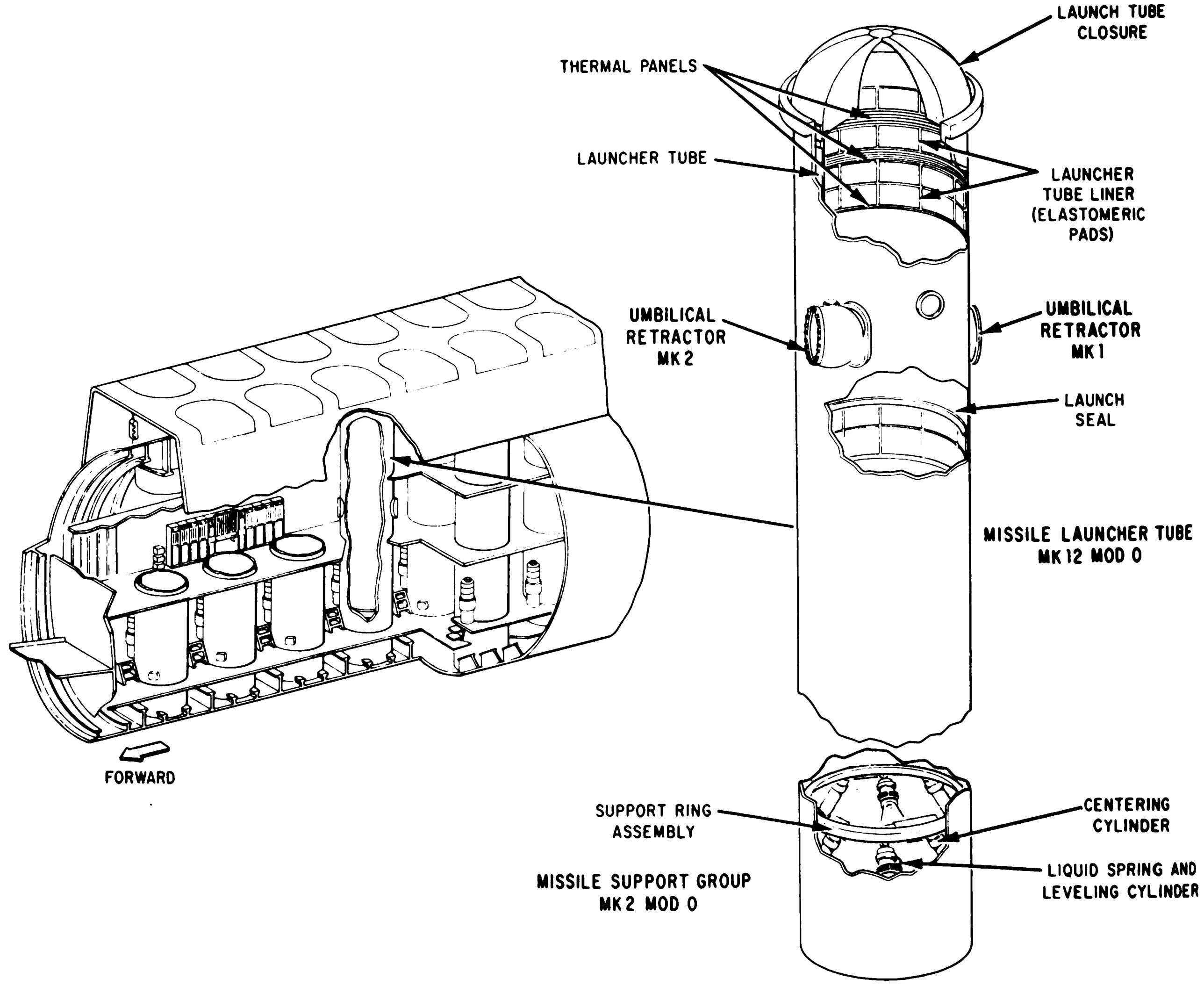

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Figure 11-1.—Missile launcher tube, support group and umbilical retractors (Mk 24 System).

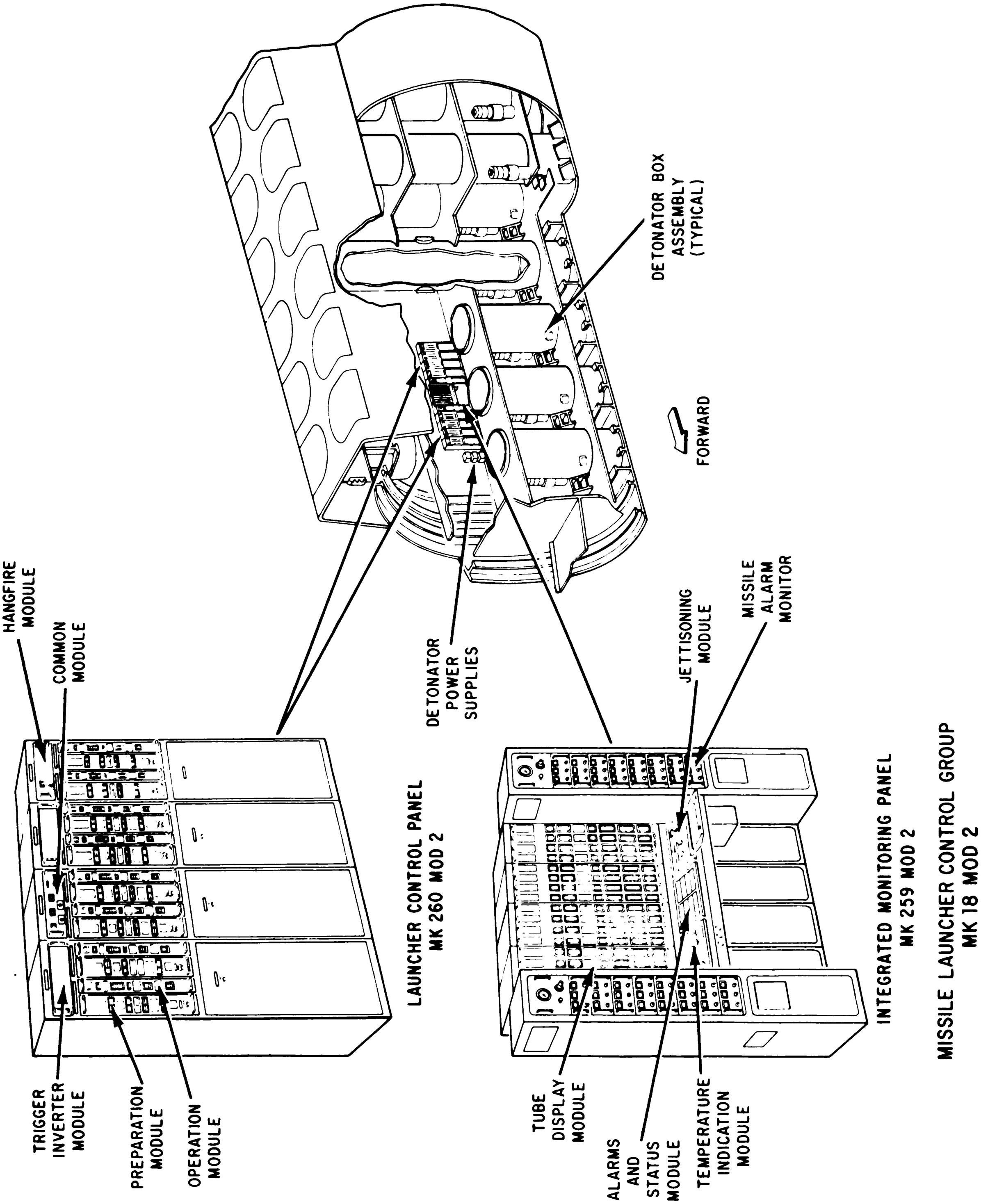

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Figure 11-2.—Missile launcher control group (Mk 24 System).

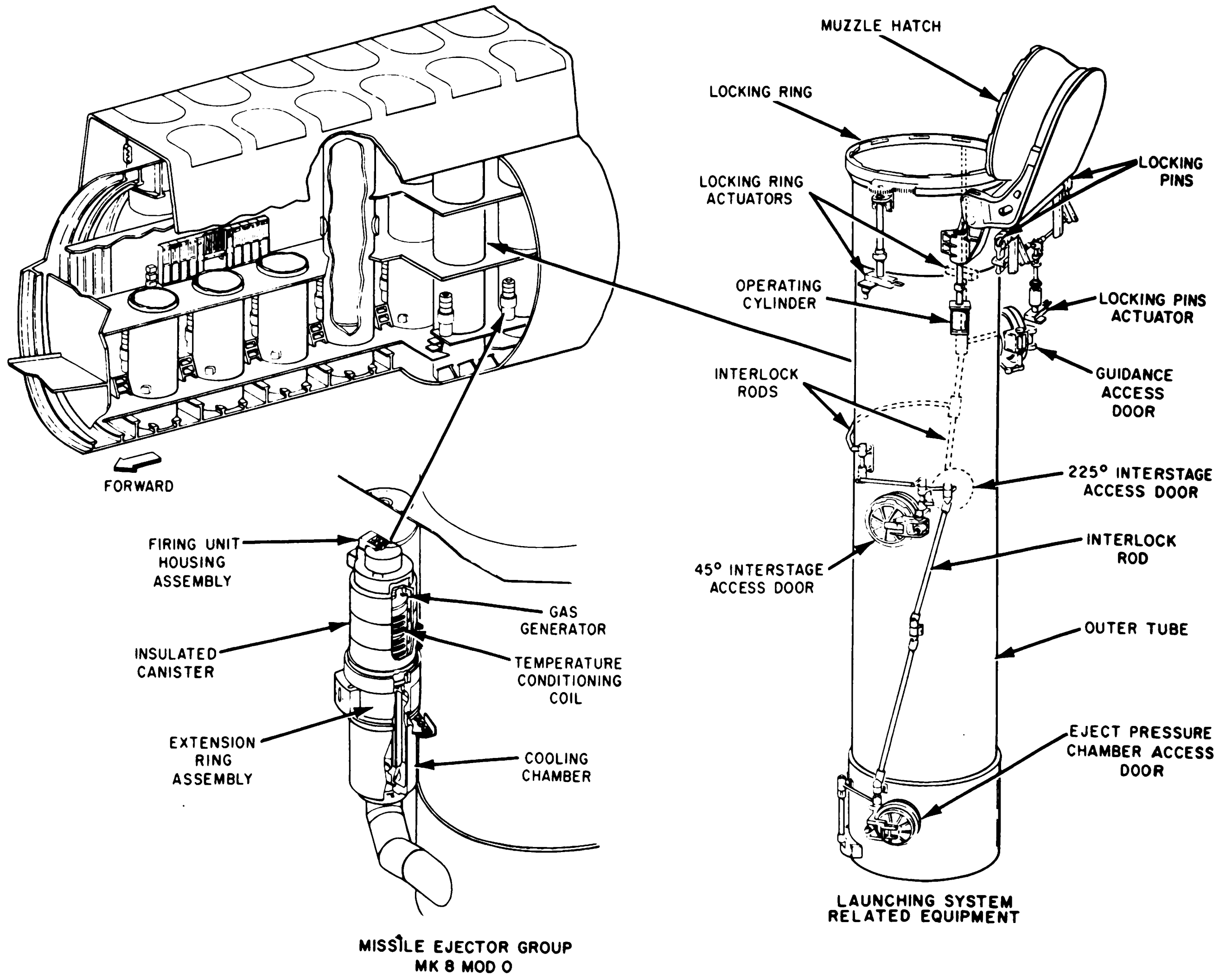

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Figure 11-3.—Missile ejector group and missile launching system related equipment (Mk 24 System).

LAUNCHER TUBE ASSEMBLY.—The launcher tube assembly provides lateral support and shock protection for the missile during storage and ejection. The assembly consists of a launcher tube, a launcher tube liner, launch seals, and thermal panels.

The launcher tube itself is 29 feet 6 inches long and has a 77-inch inside diameter. The tube has 15 penetrations-access doors, electrical and pressurization connections, umbilical retractors, and optical viewing windows.

The launcher tube liner consists of elastomeric pads (refer to fig. 11-1) bonded to the launcher tube. These pads, coated with Teflon to reduce friction with the missile, provide both lateral support and shock protection for the missile.

Six launch seals positioned at various levels around the launcher tube and adjacent to the liner pads, limit the launch pressures on the missile skin to an acceptable level during launch. The surface that touches the missile skin is also coated with Teflon.

Three sets of stainless steel circumferential bands (thermal panels) of heat transfer elements maintain ambient temperature at the forward end of the missile by circulating heating or cooling water as necessary from the missile heating and cooling system.

LAUNCHER TUBE CLOSURE.—The launcher tube closure seals the launcher tube from outside environment when the muzzle hatch is open. The closure is divided into 10 segments. At missile launch, a shaped explosive charge system arranged on the closure is detonated and the closure is separated into eight pie-shaped and two semicircular pieces (fig. 11-4). Rupture of the closure must occur in such a manner as to permit exit of the missile without damage and without having the missile trajectory affected by the closure. Detonation of the explosive charge is initiated at missile first motion by departure switches on the support ring. Eight detonators, four instantaneous and four delayed, detonate the explosive charge. The instantaneous detonation causes the separation of the closure dome from the launcher tube as well as the separation of the two semicircular pieces at the top of the closure. The delayed detonation, milliseconds later, causes the eight pie-shaped segments to separate.

### Missile Support Group Mk 2 Mod 0

The missile group maintains the missile concentric with the launcher tube, prevents additional missile misalignment in the launcher tube, and provides vertical shock protection for the missile. The support group is installed in the eject pressure chamber and consists of four liquid spring and leveling cylinder (LSLC) assembiles, four centering cylinders, and a missile support ring assembly (refer to fig. 11-1).

LIQUID SPRING AND LEVELING CYLINDER ASSEMBLIES.—The liquid spring and leveling cylinder assemblies provide equally

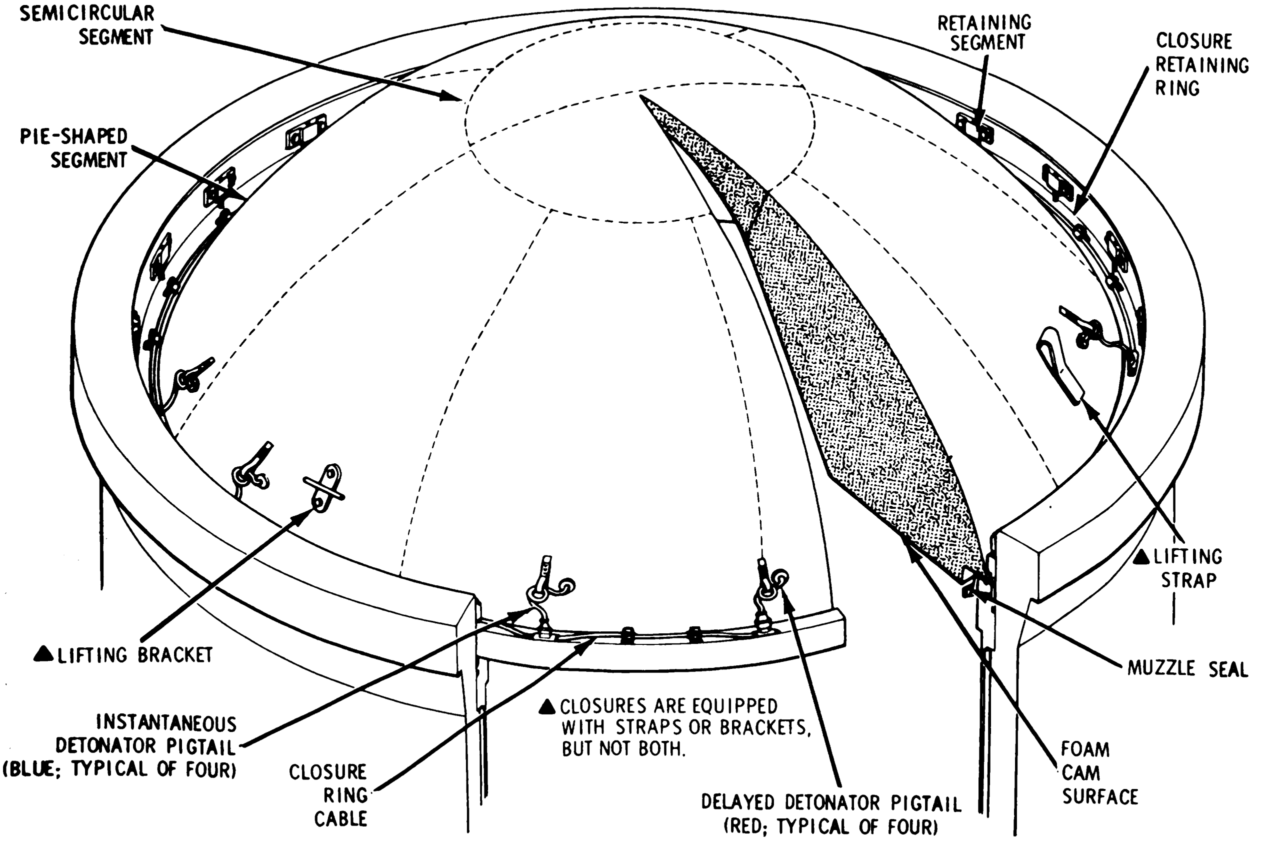

SEMICIRCULAR SEGMENT
RETAINING SEGMENT
CLOSURE RETAINING RING
PIE-SHAPED SEGMENT
▲LIFTING STRAP
▲LIFTING BRACKET
MUZZLE SEAL
▲CLOSURES ARE EQUIPPED WITH STRAPS OR BRACKETS, BUT NOT BOTH.
INSTANTANEOUS DETONATOR PIGTAIL (BLUE; TYPICAL OF FOUR)
CLOSURE RING CABLE
DELAYED DETONATOR PIGTAIL (RED; TYPICAL OF FOUR)
FOAM CAM SURFACE
33.471

Figure 11-4.—Launcher tube closure.

divided vertical support for the missile. Each LSLC assembly has two separate functions. The liquid spring occupies the upper end of the cylinder and provides vertical support and shock mitigation for the missile. The leveling cylinder occupies the lower end of the cylinder and adjusts the support ring horizontal plane to conform to the missile skirt during procedures. After the missile is loaded into the tube, the leveling cylinder, connected between the support ring and the ship's hull, is locked in place.

CENTERING CYLINDERS.—Four cylinders (refer to fig 11-1) maintain the support ring concentric with the launcher tube when a missile is not installed. Each cylinder is connected between the support ring and the wall of the eject pressure chamber. After missile installation, the cylinders extend or retract as necessary without interfering with the movement of the support ring.

SUPPORT RING ASSEMBLY.—The support ring assembly (refer to fig. 11-1) vertically supports and ensures azimuthal alignment of the stowed missile, provides missile away or in-place indications, provides humidity status indications and initiates detonation of the launcher tube closure explosive charge. The assembly consists of the support ring, two departure switch assemblies, an antirotation key, and associated electrical installations.

The support ring provides a seat for the missile and a mounting surface for the components of the support ring assembly. During loading, the missile is guided onto the seating surface by a lip on top of the support ring. The leveling system compensates for any misalignment between the missile skirt and the support ring. The support ring also contains detectors for monitoring lower zone temperature and humidity. Each departure switch assembly actually contains two switches, one for indications and the other for closure detonation. When a missile is seated on the support ring, the switch plunger is depressed, providing an indication that the missile is in place. At missile first motion, the missile lifts off the support ring and releases the switch plungers, initiating detonation of the closure and providing an indication of missile away. The two departure switch assemblies are redundant for fail-safe operation. The antirotation key is installed by the lower-level missile handling team in a slot through the support ring at 37° azimuth to prevent missile rotation after onloading and final azimuth alignment is completed.

### Umbilical Retractors Mk 1 and Mk 2

The umbilical retractors (refer to fig. 11-1) withdraw the umbilical plugs from the missile at launch. When missile first motion occurs, the umbilical plugs are disconnected through cam action initiated by the upward travel of the missile. After initial disconnect from the missile, the umbilical plugs are retracted and locked into place by a gas-operated piston assembly. Gas pressure for the retract mechanisms is available from an eject entry pipe pressure tap. Umbilical Retractor Mk 1 is located at 45° azimuth, and Umbilical Retractor Mk 2 is located at 310° azimuth.

### Missile Launcher Control Group Mk 18 Mod 2

The missile launcher control group controls and monitors the launching system during loading, cruising, launching, and jettisoning operations. The control group (refer to fig. 11-2) consists of two Launcher Control Panels (LCPs) Mk 260 Mod 2, one Integrated Monitoring Panel (IMP) Mk 259 Mod 2, 16 EBW firing units, three detonator power supplies (two active, one spare), and 16 detonator box assemblies.

In looking over the main components of the launcher control group of the Mk 24 launching system, we can see that there is an integrated monitoring panel, and circuitry associated with the closure detonation network. Before proceeding to the actual operation of this control group, let's look at the association of the technician with this complex portion of the Mk 24 launching system.

The central portion of the launcher control group (two LCPs and IMP) is located in the middle-level missile compartment. This area is continuously manned underway or in port and is designated as the launch operation station (LOS) watch. There is also an assistant (ALOS) continuously available to the LOS underway, as needed, and a roving patrol who monitors the entire missile compartment underway and in port. The LOS is continuously monitoring the status of the missiles, missile tubes, firing units, muzzle hatches, valve lineups, and hydraulic and pneumatic operating pressures utilizing IMP and the two LCPs. Corrective action is taken as necessary. During a tactical launch, the monitoring and operation of the launcher central area are carried out by four or more personnel.

There are various colors of indications on the LCPs and IMP with which you should be familiar. The colors of the indications and their meanings are as follows:

1. Blue—Command
2. Green—Condition safe for launching or cruising
3. Red—Malfunction or condition requiring corrective action
4. White—Static condition or action complete
5. Amber—Condition requiring monitoring

Each indicator light has two lamps for reliability. For ease of replacement, the lamp-holders are pivoted to rotate out from the modules.

LAUNCHER CONTROL PANEL MK 260 MOD 2.—The launcher control panels (LCP 1 for missiles 1-8 and LCP 2 for missiles 9-16) provide control and monitoring of the launching system operations and missile tube pressurization and provide the interface between the launching and fire control systems. Each LCP consists of one common module, eight preparation modules, eight operation modules, one hangfire module, and two trigger/inverter modules (TIM).

The common module enables selection of launch mode and pressurization supply and displays status conditions common to the entire launching system. The launch mode switch allows the selection of SURFACE or SUBMERGED launch. SUBMERGED position on one common module will override SURFACED position on the other common module. The pressurization supply switch allows the selection of NITROGEN or AIR for pressurizing launcher and supplying control gas for the breather valve (NITROGEN will normally be selected for a tactical launch). NITROGEN position on one common module will override AIR position on the other common module. Indications on the common module and their meanings are as follows:

1. POWER ON—Power is available at the LCP
2. LCC MODE SW. NORMAL—Fire control circuits are connected to launcher and the missile compartment
3. AIR—Air supply isolation valve is positioned for pressurizing with air
4. NITROGEN—Nitrogen supply isolation valve is positioned for pressurizing with nitrogen
5. NITROGEN SUPPLY LOW—Pressure in nitrogen bank has dropped to 1000 ±50 psig. (Pressure has to increase to 1200 ±50 psig to clear alarm)

The trigger inverter module (TIM) develops and distributes charge and trigger signals to an associated gas pressure generator EBW firing unit. Each TIM (two on each LCP) contains four trigger/inverter units. Each unit charges a firing capacitor and triggers a gap switch in the EBW firing unit that releases the charge, firing the EBW initiator.

The hangfire module monitors for a hangfire condition that causes a system hold to be generated and displayed. A hangfire condition occurs when a missile away signal is not indicated on the LCP within one second after the EBW initiator receives the firing pulse. A switch is provided to release the system hold on all launchers except the affected one. A SYSTEM HOLD indication is also displayed on the module, the affected missiles at the Fire Control Console, and the Attack Center Indicator Panel (ACIP).

The preparation modules (eight on each LCP) control access to the missile tubes and monitor the preparation functions of missile launch. Switches control the operation of the mechanical interlocks that permit access to the missile tube and the selection of the mode of breather valve operation. Indicators display the status of the access doors, missile tube pressurization, and the ejector group equipment.

The operation modules (eight on each LCP) enable selection of local or remote control of the missile tube denote sequence and muzzle hatch (MH) operation; display missile tube pressurization, MH operation, and missile away status; and control the generation of hold commands to halt missile launch preparation for its associated missile tube.

INTEGRATED MONITORING PANEL Mk 259 MOD 2.—The integrated monitoring panel monitors and displays the status of critical missile and launcher tube circuits, generates an MC (missile compartment) hold for certain critical conditions, and permits local control for emergency missile jettisoning. The panel consists of 16 tube display modules, a temperature indication module, an alarms and status module, a jettisoning module, and the missile alarm monitor. This panel is the central monitoring station for the LOS watchstander of the Mk 24 system.

The tube display module monitors and displays the status of critical circuits for one launcher tube and its associated missile, as well as the status of the missile in the launch sequence. On the tube display module, there are actuator/indicators (A/Is). This indicator also contains a pushtype switch which, when depressed by the LOS watchstander, activates other circuits in the launcher.

The temperature indication module, monitors launcher tube air and its associated missile and operating conditions common to all tubes. The module contains an A/I for each tube and A/Is and indicators for conditions common to all tubes. When an abnormal condition affects the missile or tube, its associated A/I will light red, and an audible alarm will sound. Depressing the A/I displays the condition at the tube display module, silences the alarm, and changes the indication to amber.

The jettisoning module, provides the capability for emergency missile jettisoning. The module front panel is protected by a key-locked cover. When the cover is opened by a sensitive key (special handling and custodial requirements), a ship's alarm is sounded. Opening the cover permits access to switches that enable selection and initiate ejection of the missile. Jettisoning will only be carried out in an extreme emergency by the weapons officer in strict compliance with applicable weapons operating procedures.

The missile alarm monitor (MAM) monitors for the correct configuration of missile ignition inverter installation. The Missile Technicians install the ignition inverters for the 1SQ and 2SQ conditions and remove them for the 3SQ and 4SQ conditions. The monitor consists of two cabinets (refer to fig. 11-2), a left-hand cabinet that monitors missile 1 through 8, and a right-hand cabinet that monitors missiles 9-16.

DETONATOR POWER SUPPLIES.—The detonator power supplies (refer to fig 11-2) convert 450-volt a.c. 60-Hz power to 50-volt d.c. for distribution to the 16 detonator box assemblies. Two of the supplies are active, and one is a spare. The spare, if needed, must be wired or patched into the system.

DETONATOR BOX ASSEMBLIES.—The detonator box assemblies (refer to fig. 11-2) provide the circuitry required to deliver power from the detonator power supplies to the departure switches for subsequent distribution to the launcher tube closure detonators. This group consists of 16 assemblies, one mounted on each outer tube in the lower-level missile compartment.

EXPLODING BRIDGEWIRE FIRING UNIT.—The exploding bridgewire (EBW) firing unit, stores and releases the 2250 ± 250-volt d.c. charge necessary to fire the EBW initiator in its associated gas generator. The EBW firing unit is enclosed within the EBW firing unit housing assembly (refer to fig. 11-3). The unit is made ready by lower-level technicians who position it from the SAFE to the READY position using a sensitive key. The position of the switch is monitored continuously on the preparation module of the LCPs.

MISSILE EJECTOR GROUP MK 8 MOD 0.—The missile ejector group systems Mk 24 uses a pressurized mixture of gas, steam, and water to launch the missile. This gas, steam, and water system of the Mk 24 ejects the missile with a uniform pressurization rate. The missile ejector group is made up of a firing unit housing assembly, a Propellant-Actuated Gas Pressure Generator Mk 50 Mod 0, a cooling chamber, and an insulated canister (refer to fig. 11-3).

The gas generator is a solid-propellant chamber mounted vertically atop the cooling chamber assembly. At launch, the gas generator is ignited, creating a rapid buildup of pressure within the cooling chamber. As a result of this pressure, water is forced out of the cooling chamber, through a series of metering holes in a standpipe traversing the length of the cooling chamber. Hot gases, exhausting at a programmed rate from the gas generator, pass through the standpipe, where they are mixed with the water from the cooling chamber. This lowers the temperature of the gases, thus averting the danger of premature missile ignition. The resultant mixture of gas, water, and steam passes through a ruptured water closure, through the launch gas entry pipe into the eject pressure chamber to launch the missile. Fail-safe devices and circuits prevent inadvertent launching of the missile.

The gas generator is ignited by an exploding bridgewire (EBW) which converts an electrical command into an explosive impulse. The EBW firing unit receives the launch command from the fire control system through the launcher control panel. This command could also come from the jettison control panel during emergency conditions. A key obtained from the commanding officer is used just prior to launch to switch the EBW firing unit from the SAFE to the READY position by lower-level technicians. Another key, the EBW housing ring key, locks the EBW firing unit under a housing ring and prevents any tampering with the firing unit. Another safety precaution is the continuous monitoring of the ejector water level at the launcher control station prior to launch.

### Related Equipment

Also illustrated in figure 11-3 are various related equipment of the Mk 24 launching system, such as the outer tube, access doors, and the interlock rods. These mechanical interlocks safeguard against flooding of the missile compartment by preventing simultaneous opening of the access doors and the muzzle hatch or the compensating sea valve. Rods are locked in place and prevented from rotating by a solenoid-actuated locking pin controlled at the LCP. Also of some note in the illustration are the locking pin and locking ring mechanisms of the muzzle hatch.

### Pressurization System

Before concluding the discussion of the Mk 24 launching system by briefly describing its functional operation, there is one other important subject that should be covered. This is the missile pressurization system shown in figure 11-5. The pressurization system pressurizes and maintains the missile tube to a positive differential pressure above sea pressure during a submerged launch. Pressurizing the missile tube prior to a launch pressurizes the interior of the missile through various breathe holes. This enables the missile to withstand the sea environment after the missile is ejected from the tube. In addition, pressurization aids in opening the muzzle hatch against sea pressure and supports the missile tube diaphragm after the muzzle hatch is opened.

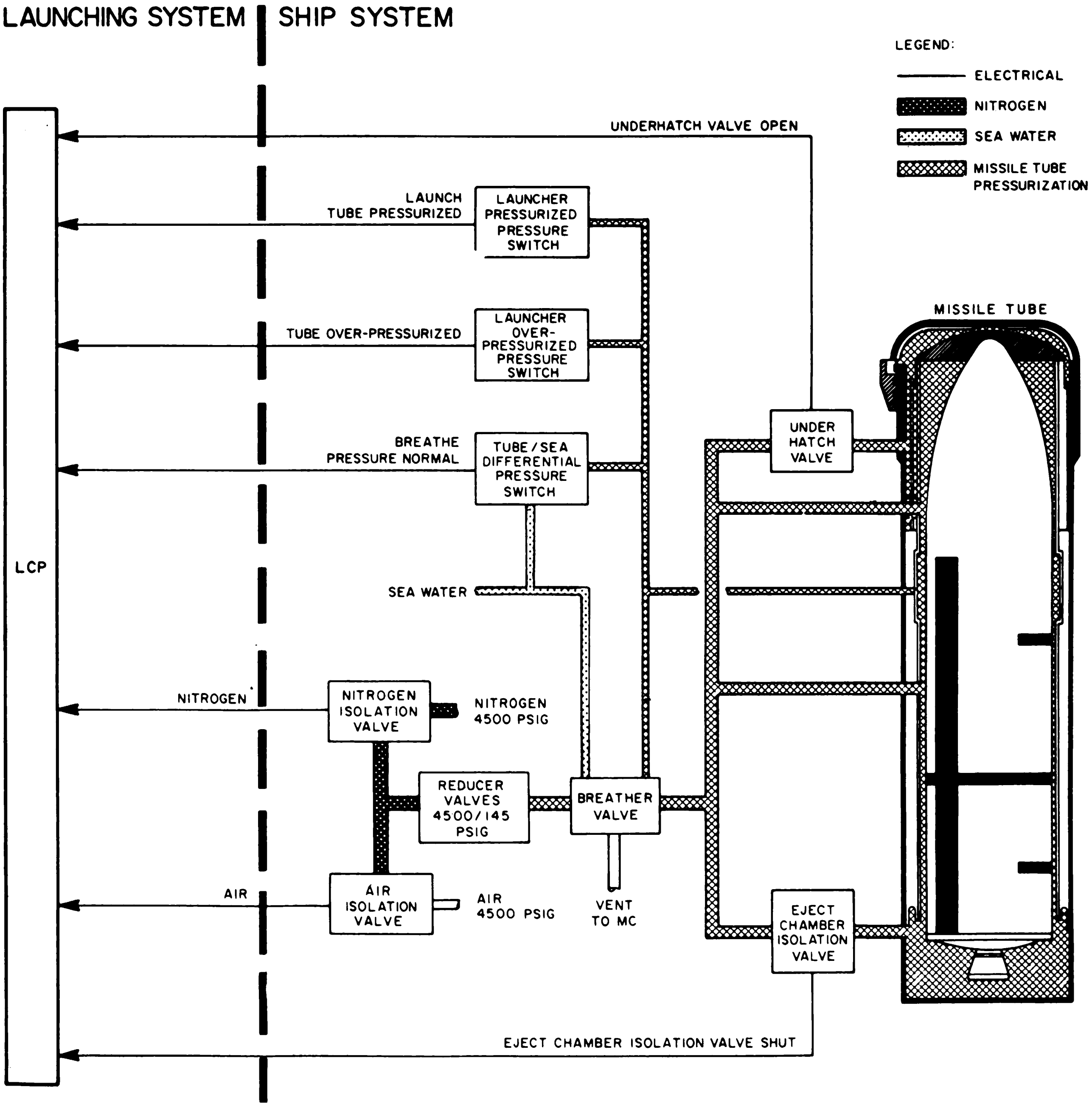
The pressurizing agent, selected at the LCP common module, is either nitrogen or air. The nitrogen or air is supplied from the missile gas system. Air is used for pressurization during training missile launching operations of the Mk 24 system. Nitrogen is used with the Mk 24 systems during tactical missile launching operations because of its inerting capabilities on the hot gases of the expended gas generators.

A breather valve in the pressurization system controls the flow of air or nitrogen into and out of the missile tube. Each missile is equipped with two breather valves (one active, one on standby). In the event of an active breather valve failure, the standby breather valve has to be manually shifted into operation by the technician. The breather valve can be operated in three different manners: (1) manually at the breather valve, (2) remotely from the LCP, or (3) automatically.

BREATHER VALVE.—Breather valve operation maintains the desired pressure in the missile tube. As stated above, the breather valve can be operated in one of three separate modes: automatic, remote, and manual. For a tactical launch, the automatic mode is selected. However, various casualty situations could develop that would lead to operation of the breather valve in one of the other modes.

### MK 24 Functional Operation

When the commanding officer (CO) issues the command MAN BATTLE STATIONS MISSILE FOR STRATEGIC LAUNCH, a series of events takes place while the launch orders are being authenticated and prior to the command SET CONDITION 1SQ FOR STRATEGIC LAUNCH being issued. The launcher supervisor opens the forward and aft hydraulic supply valves for the missile tube hydraulics. The LCP operators set the pressurization supply switch to NITROGEN, verify that the launch mode switch is set to SUBMERGED, and that the breather valve switches are set to SHUT. The LCP operators set the denote switches to LOCAL the muzzle hatch switches to REMOTE for all tubes. The breather valve switches for the first four tubes are set to AUTO after the sea sensing lines have been opened, initiating missile tube pressurization. When missile tube pressure approximately corresponds to sea pressure at the ordered depth, the

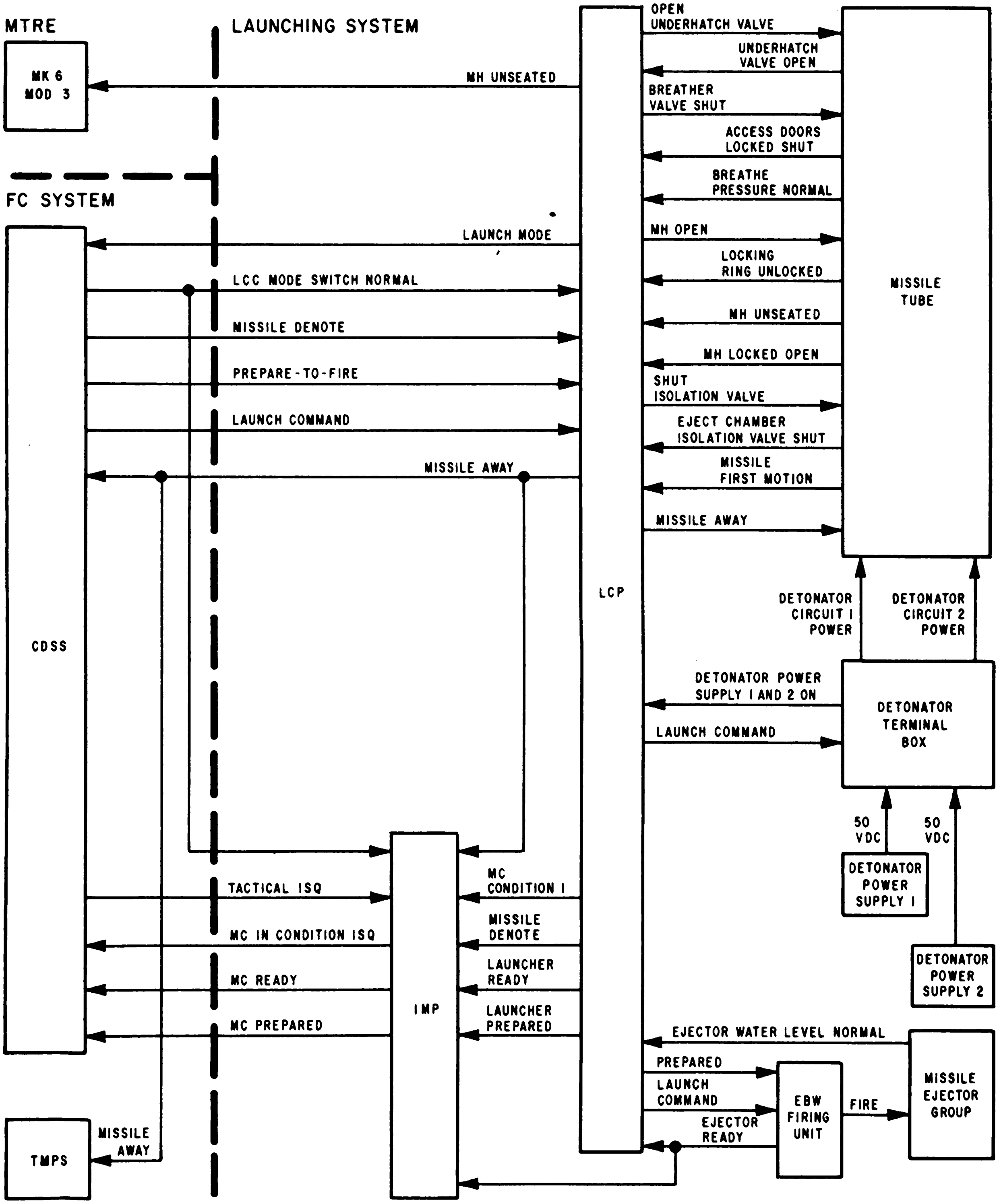


33.473

Figure 11-5.—Missile tube pressurization (Mk 24 System).

denote switches are set to REMOTE. The procedure is repeated for the remaining tubes in accordance with the firing order, in groups of four, until all tubes are pressurized.

When the CO issues the command SET CONDITION 1SQ FOR STRATEGIC LAUNCH, the arming crew manually unlocks the EBW firing units, and IMP and LCPs receive an LCC mode switch normal from fire control showing that the interface between the two systems is ready for the launch (see figure 11-6).



33.474

Figure 11-6.—Launching system control and monitoring (Mk 24 System).

When all the above conditions have been met, the LCP routes an MC conditon 1 signal to IMP, resulting in an MC-in-condition-1SQ signal to fire control. This indicates that the launching system is ready to proceed with the launch sequence. The MC condition 1 signal is a result of the following conditions:

1. Missile in place
2. No IMP holds
3. No LCP holds
4. Access doors locked shut
5. Breather valve in AUTOMATIC
6. DENOTE switch in LOCAL or REMOTE
7. MUZZLE HATCH switch in REMOTE or OPEN
8. Ejector group water level normal
9. Closure detonator power on
10. Firing unit SAFE/READY switch in READY

The final portion of the launch sequence is initiated when the CO grants permission to fire after the weapon system is at condition 1SQ. The denote sequence is initiated by the fire control system when the control and display subsystem (CDSS) routes a missile denote signal to the LCP. The LCP routes the missile denote signal to IMP and removes the breather valve shut command from the missile tube. When the shut command is removed, the breather valve again enters the automatic breathe mode. The missile tube is further pressurized to slightly above sea pressure at launch depth. When this pressure is attained, the missile tube routes a breathe-pressure-normal signal to the LCP, indicating the missile tube is pressurized. With breathe pressure normal and the EBW firing unit unlocked, the LCP generates and routes a launcher ready signal to IMP, which routes an MC ready signal to CDSS, indicating that the launching system has completed the denote sequence.

The muzzle hatch opening sequence is initiated by the receipt of the prepare-to-fire signal from fire control. The LCP generates and routes an MH open command to the missile tube. This initiates the following chain of events which are locally monitored by upper-level technicians:

1. Locking ring unlocks
2. Under-the-hatch-valve commanded shut
3. Hatch opens
4. Hatch unseated sent to MTRE to allow the transfer to internal power
5. Hatch locked open by locking pins and locked open indication sent to LCP

After the muzzle hatch is locked open, the LCP operator sets the eject system switch on the LCP to prepared, routing a prepared signal to the EBW firing unit and a launcher prepared signal to IMP. The prepared signal causes capacitors within the EBW firing unit to charge. Upon receipt of the launcher prepared signal, IMP generates and routes an MC prepared signal to CDSS (refer to fig. 11-6).

When CDSS receives the MC prepared signal and all the weapon system functions are complete, a launch command is routed to the LCP. Upon receipt of the launch command, the LCP routes the breather valve shut command and a shut isolation valve command to the missile tube and routes the launch command to the detonator terminal box and the EBW firing unit. The breather-valve-shut command shuts the breather valve to prevent it from flooding after ejection of the missile. The shut-isolation-valve command energizes a solenoid control valve that allows ship's hydraulics to shut the valve to prevent steam blow-by during missile launch.

Upon receipt of the launch command, the detonator terminal box routes the 50-volt d.c. power from the detonator power supplies to the missile tube departure switches as detonator circuit 1 power and detonator circuit 2 power.

Upon receipt of the launch command, the EBW firing unit capacitors discharge, routing a fire signal to the EBW initiator in the missile ejector group. At ignition of the gas generator, a mixture of gas, steam, and water enters the eject pressure chamber to smoothly eject the missile.

When the missile lifts off the missile support ring, the departure switches deactivate. The departure switches route detonator circuit 1 and 2 power to the launcher tube closure detonators. The detonators set off charges to rupture and separate the tube closure, clearing the way for missile passage. The departure switches also route a missile-first-motion signal to the LCP. The LCP then generates and routes a missile away signal to the following places:

1. Missile tube—Causes the solenoid controlled guidance coolant supply and return valves to shut—prevents contamination of this fresh water system by seawater.

2. IMP—Inhibits IMP from monitoring an expired missile tube.

3. CDSS—Enables the fire control system to prepare for the next missile in the firing order.

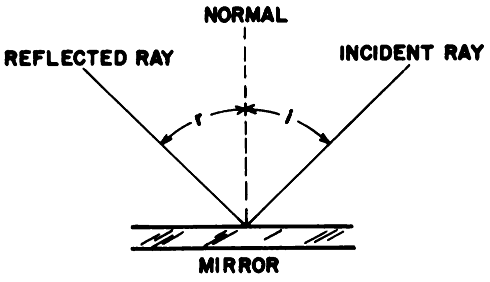
4. TMPS—Resets TMPS, removing guidance power from the expired missile tube.

## MLS SUMMARY

This section should be used as an introduction to the launching system. For further technical information, refer to NAVORD OP 3736 for the Mk 24 launching system. Major launcher evolutions and emergency procedures are specified in the operating manual for the system. This manual is divided into procedural guides (PGs), weapons procedures (WPs) and casualty procedures (CPs) which are to be strictly adhered to in carrying out any of these evolutions. This manual is NAVORD OD 43144 (Mk 24).

## OPTICAL PRINCIPLES

Before going into the optical system we will briefly examine some of the properties of light. To start with, light is a form of energy that is considered to travel in wave form. The waves move outward from the source as a series of concentric, rapidly expanding spheres. In the study of optical instruments, it is convenient to trace the path of light rays rather than waves. A ray is an imaginary line used to show the direction in which the light waves are moving. A ray is a radius of the sphere formed by the wavefront, and is at right angles to the wavefront. Although there is an infinite number of rays in a spherical wave, usually three rays are enough to show the path of a light beam.



12.231

Figure 11-7.—The reflection of light.

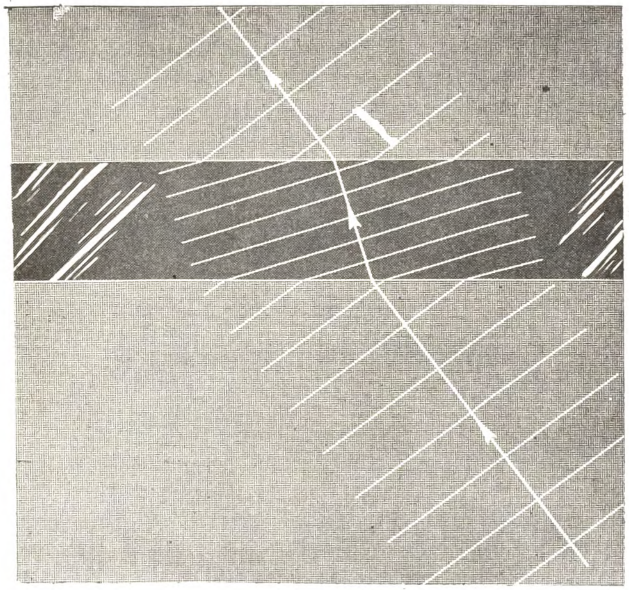
### Reflection

Figure 11-7 illustrates several of the terms used to describe the reflection of light. The incoming ray, from the source, is the incident ray. The normal is an imaginary straight line at right angles to the reflecting surface (in this case a mirror), passing through the point of incidence. The angle of incidence is the angle between the incident ray and the normal, and the angle of reflection is the angle between the normal and the reflected ray. The law of reflection states, first, that the angle of incidence is equal to the angle of reflection; and, second, that the incident ray, the reflected ray, and the normal all lie in the same plane.

When light strikes the surface of clear glass, a part of the light will be reflected and the rest will enter the glass. If the incident ray lies on the normal (zero angle of incidence) about 5 percent of the light will be reflected. As the angle of incidence is increased the amount of reflection increases. As the angle of incident approaches 90°, the reflection approaches 100 percent.

### Refraction of Light

Light travels at a speed of approximately 186,000 miles per second in air. In a vacuum, its velocity is slightly higher. In a denser medium it moves more slowly. When light passes from one medium into another of different density, its velocity changes. This change in velocity makes it possible for an optical instrument to control the path of light, to form images and to magnify them.

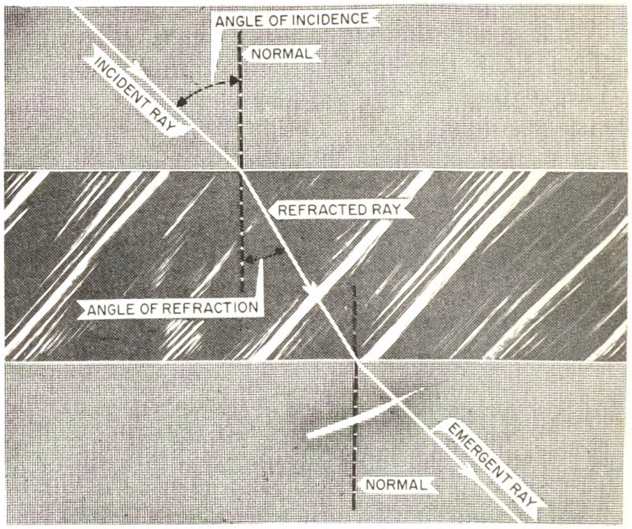


12.232

Figure 11-8.—Path of wavefronts through a sheet of glass.

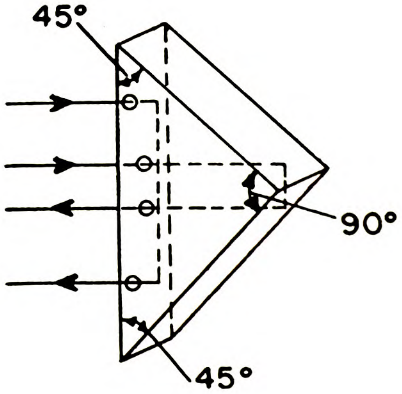
In figure 11-8, a ray of light strikes a glass at an oblique angle (any angle which is not a right angle). The approaching light waves are from a distant source, and are therefore parallel. As each wave enters the glass, various points along the wave front will slow unsuccessively and as a result the entire wave front will change its angle. Since the direction of movement, shown by the ray, is at right angles to the wave fronts, the light bends as it enters the glass. The opposite effect occurs when the waves leave the glass. Now the various points along the wave successively increase their speed. As a result, the emergent waves are parallel to those that entered the glass, and the emergent ray is parallel to the incident ray, although it has been displaced to one side.

Figure 11-9 illustrates some of the terms used to describe the refractions or bending of light. The law of refraction states that light bends toward the normal when it passes into a denser medium; it bends away form the normal when it passes into a less dense medium. The exact angle of refraction depends on the angle of incidence, and on the optical density of the two media. (The index of refraction of a vacuum is one.)



12.233

Figure 11-9.—Terms used to describe the refraction of light.



177.82

Figure 11-10.—The porro prism.

## Total Internal Reflection

A critical angle exists where no light can be transmitted through the boundary separating two media. The critical angle is the value at which the refractive angel becomes 90°; beyond this point all light is reflected internally. Total reflection causes the boundary to act as a mirror.

If a prism is cut as shown in figure 11-10, a light ray is reflected twice inside the prism. The path of the emergent ray is parallel to, but in the opposite direction from, the incident ray. The light ray is rotated through an angle of 180°. The porro prism mounted on the outer gimbal of the missile stable platform is cut in this manner. A five-sided prism is called a pentaprism (fig. 11-11). It will deviate the incident ray exactly 90°. A pentamirror unit (fig. 11-12) will also deviate the incident ray through 90°. The unit is a combination of two mirrors mounted 45° to each other. The deviation is in accord with the law of reflection. A ray reflected successively by two mirrors will be deviated from its original direction by an angle equal to twice the angle between the two mirrors.

## Optical Wedges

The misalignment angle is measured by deviating a light beam from its original path so that it will strike the porro prism perpendicularly. Therefore, the angle of refraction necessary to measure Bdoem will vary between missiles. A prism cut in the shape of a wedge can be rotated to provide a variable refraction angle. The direction of deviation is toward the thick side of the wedge (fig. 11-13). A ray passing through the wedge will be shifted in azimuth by a rotation of the wedge. The amount the wedge is rotated in order to shift the ray so that it will strike the porro prism at a 90° angle is proportional to Bdoem.

One difficulty remains. When the wedge is rotated, the ray will also be shifted in the vertical direction. To eliminate the vertical displacement a second wedge is placed in the light path (fig. 11-14). The second wedge is a duplicate of the

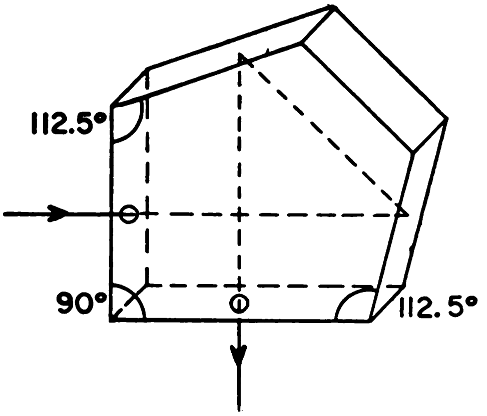


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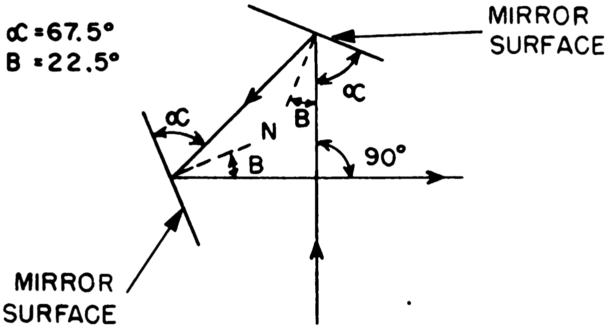
Figure 11-11.—The pentaprism.



177.83

Figure 11-12.—The pentamirror.

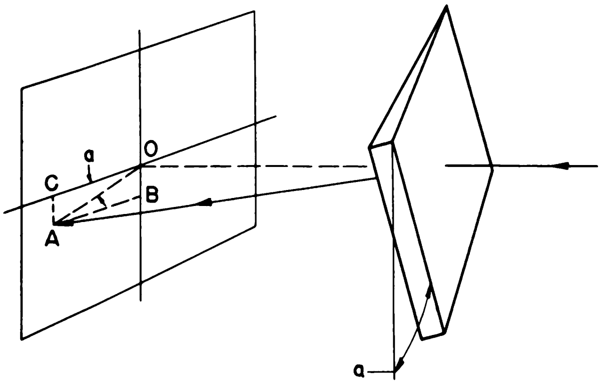


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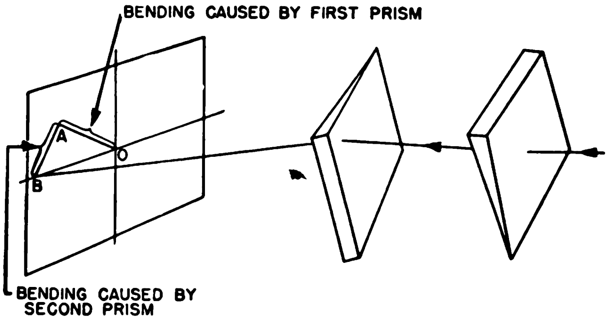
Figure 11-13.—Effect of rotating an optical wedge.



55.296

Figure 11-14.—Effect of rotating two optical wedges.

first wedge and is rotated an equal amount but in the opposite direction. The total deviation of the ray is the vectorial sum of the deviations caused by both wedges. In this arrangement the vertical deviations will cancel and the azimuth deviations will add.

### Collimation

The light that enters a lens is only a small part of a sphere. If the light wave comes from a nearby source, the rays will be diverging and the wavefront will be strongly curved (fig. 11-15). Each ray that enters a convergent lens will have a different angle of incidence and will bend to a different degree. The ray that passes through the center of the lens is normal to both surfaces and therefore, is not refracted. The greater the distance from the center of the lens, the greater the incident angle of a ray and the greater the deviation. If the lens is perfect, all emergent rays will be parallel to the ray at the center of the lens and the wavefront will be straight.

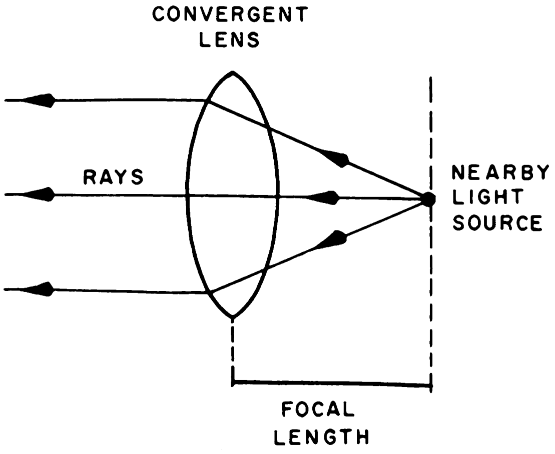


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Figure 11-15.—Collimating light rays.

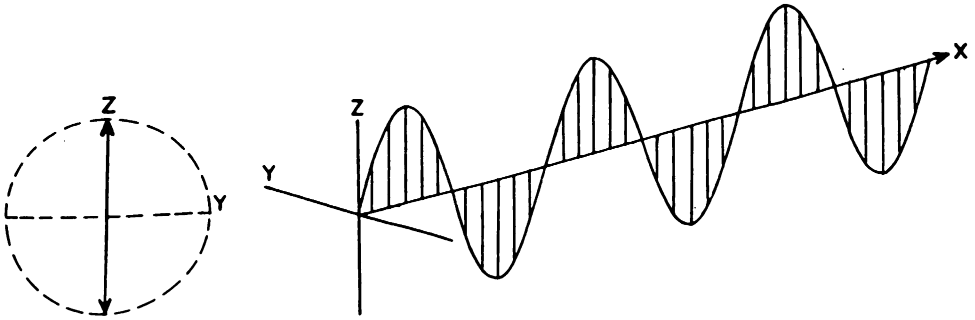
### Polarized Light

The propagation of light may be thought of as the movement of a sine wave at right angles to the direction of propagation. This is shown in figure 11-16, where the X axis denotes the direction of propagation and the Z axis denotes the magnitude of the wave. The magnitude of the wave is called the E vector. Natural or unpolarized light consists of E vectors at many angles with the Z axis (figure 11-17).

Polarized light has an E vector in one plane (figure 11-16). One method of obtaining polarized light is by passing natural light through a material known as polaroid. By properly orienting the material, the plane of polarization can be set in any direction. The resultant light is plane-polarized light and only the E vector in the plane of polarization will pass through the material. The E vectors in the other planes are inhibited.

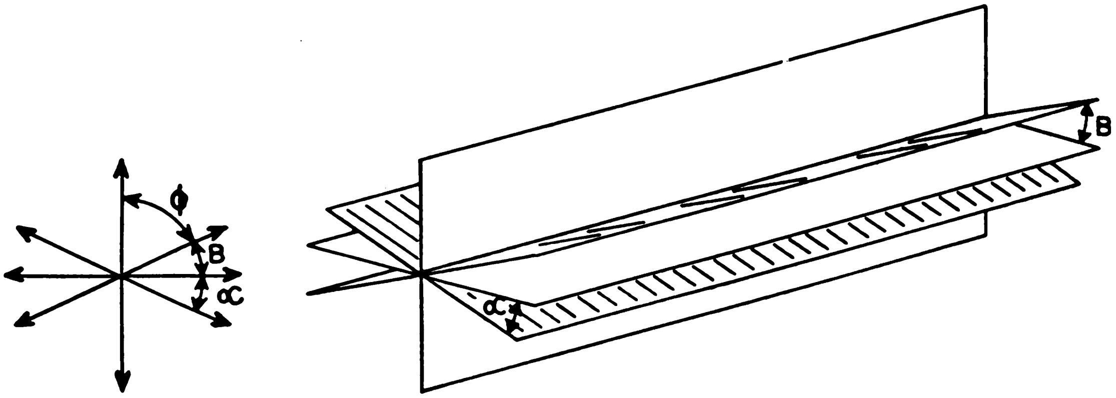
### Autocollimation

Autocollimation is the process of measuring the angular displacement between a light beam striking and leaving a remote reflecting surface. The alignment group uses a photoelectric autocollimator (PEAC) that measures the angular



177.85

Figure 11-16.—Axes used to describe light propogation.



177.86

Figure 11-17.—Graphical representation of natural light.

displacement of the missile guidance system porro prism, (and other optical reflectors), and provides an electrical error output signal.

## OPTICAL ALIGNMENT GROUP

The OAG provides an optical measure of any missile bearing misalignment angle (MBMA) in the deck planes of the missiles in the launch tubes prior to launch. The OAG equipment (fig. 11-18) is located primarily in the upper level of the missile compartment (MC). The OAG equipment provides the optical interface between the ship reference bearing axis established by the optical reference unit (ORU) and the missile reference bearing axes. The OAG measure angular physical changes, which may occur to the missile guidance reference axis with respect to the reference axis of the fire control-line-of-sight (fc-los); that is, any misalignment in the deck plane of the fc-los from the parallel established with the principal plane of the missile porro prism is monitored and measured by the photoelectric autocollimators (PEACs). The computed analog signals, which are proportional to the misalignment angles optically measured, are provided by the OAG. The analog signals of each missile are transmitted to the alignment subsystem (ALNSS) during coarse or fine alignment phases. During the coarse alignment phase, the OAG provides the static analog signals e(Bdaim) for all 16 missiles simultaneously as a result of any prior measurement of the MBMA, such as from missile on-loading alignment procedures. During the fine alignment phase, the OAG provides the dynamic MBMA signals Bdaim and q(Bdaim). The combination of these signals, Bdaim and q(Bdaim), in part, provide for the target bearing correction in the overall solution of the alignment problem. Figure 11-19 shows schematically the arrangement used by the OAG to perform the measurement function.

## MEASUREMENT FUNCTIONS

The optical line of sight (los) measurement technique used by the OAG is the method least affected by ship motion, and can operate accurately to measure angular changes in los. The los angular measurement of each missile provided by the OAG is maintained accurately over long distances within the SSBN to an established reference axis. The established reference axis is the fc-los. All OAG optical equipment is aligned to the fc-los which, in turn, is referenced to the ORU.

The OAG uses two separate optical measuring paths. The first path shown in figure 11-20, measures the Bdaim or e(Bdaim) portion of MBMA, which includes the angular rate of change induced by ship flexure. The MBMA measured in the deck plane is monitored by a PEAC whose collimated light beam is directed aft to the porro prisms of the missile guidance capsules. The second path, shown in figure 11-21, measures the

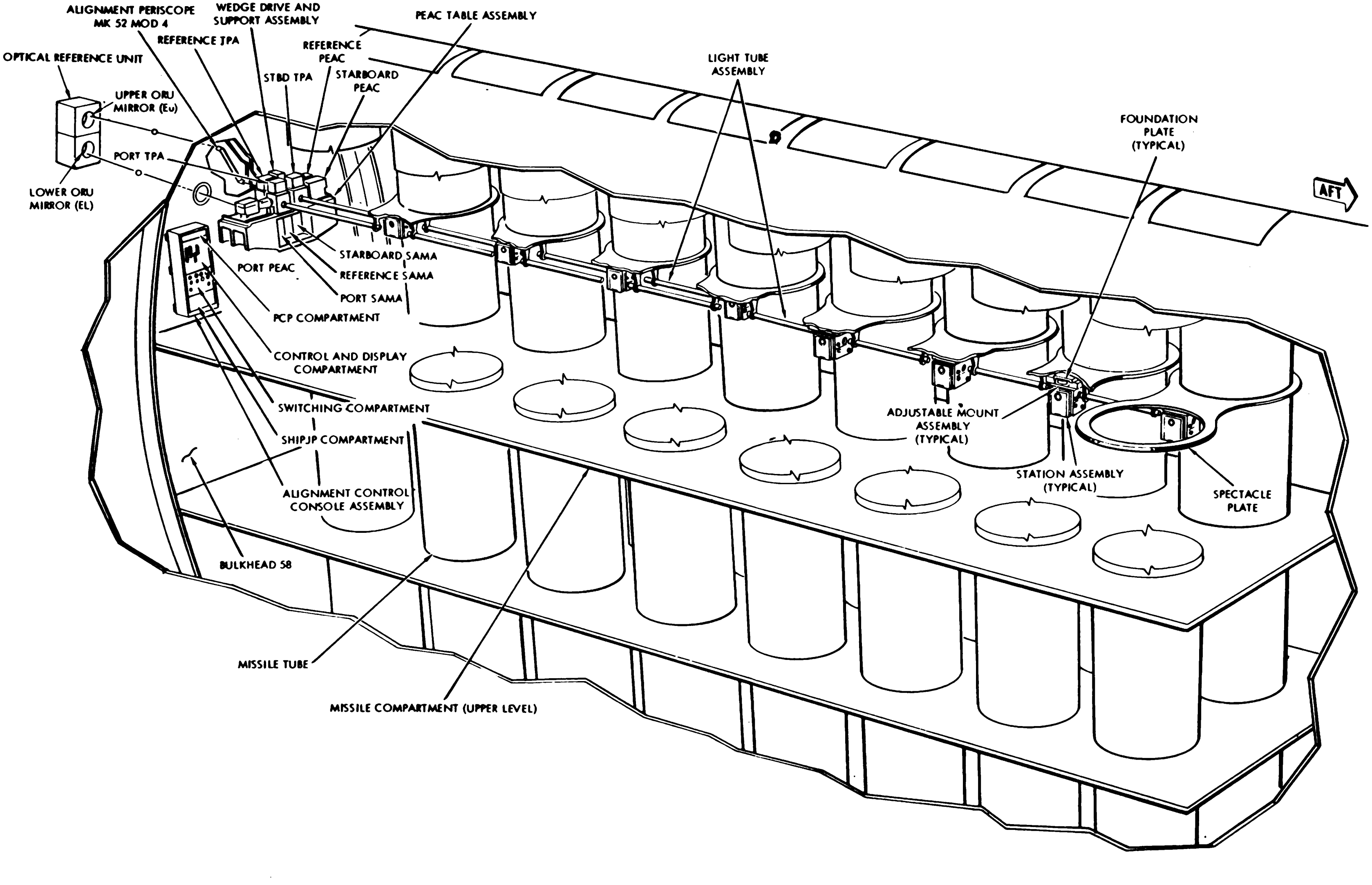


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Figure 11-18.—General arrangement of optical alignment.

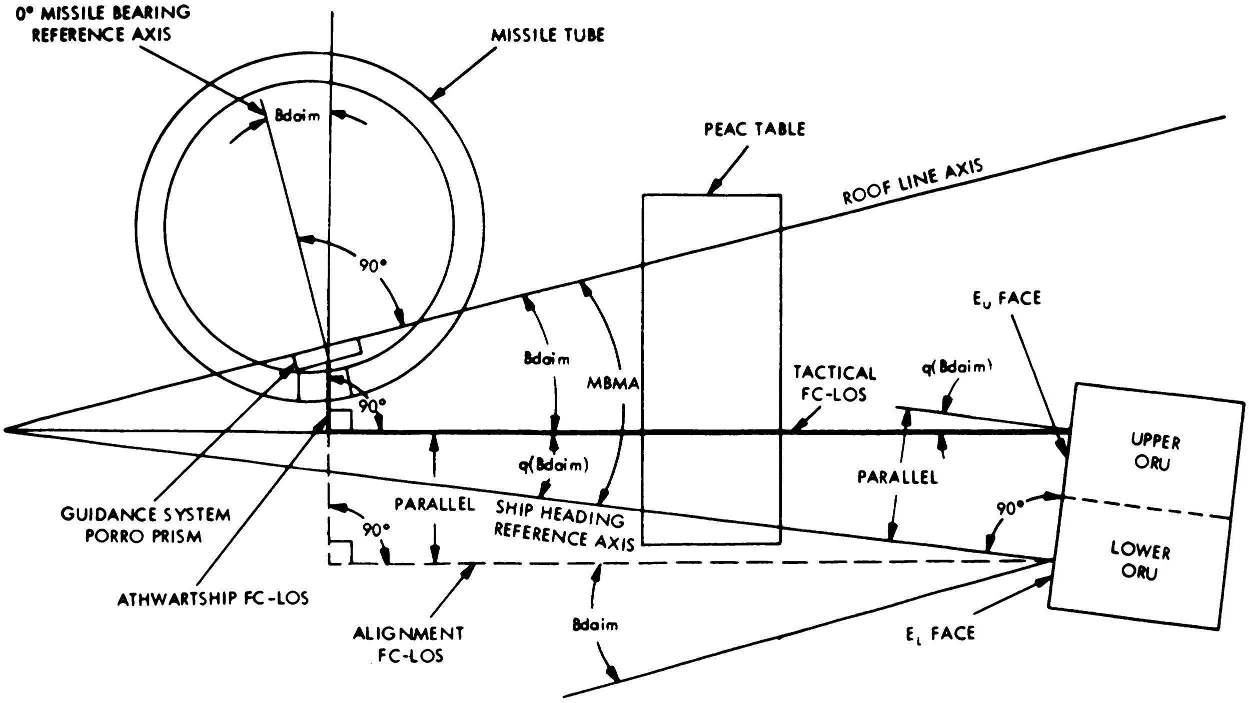

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Figure 11-19.—OAG optical interface measurement.

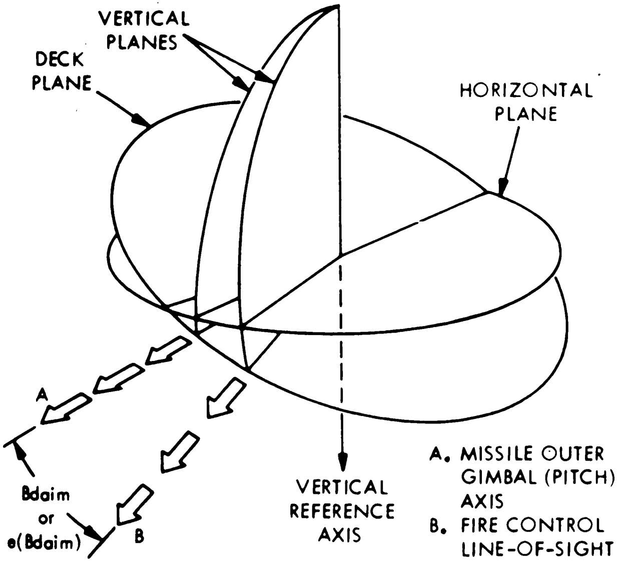

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Figure 11-20.—Bdaim or e(Bdaim).

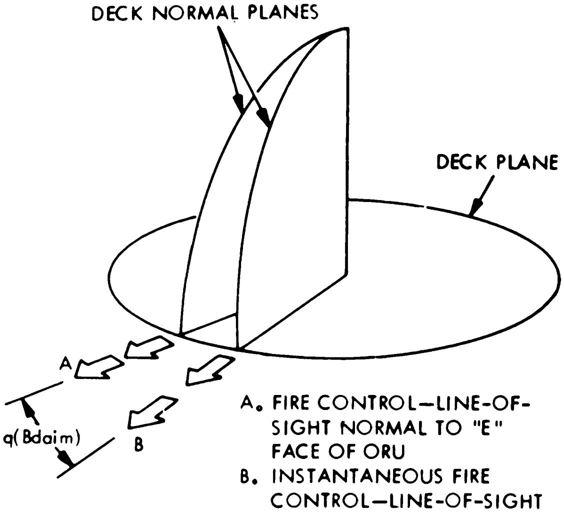

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Figure 11-21.—q(Bdaim).

dynamic portion q(Bdaim) of the MBMA as monitored by the reference PEAC. The reference PEAC light beam is transmitted forward and normal to the aft or E mirror of the ORU. The light beams of the PEACs, when aligned parallel to each other and normal to the ORU E mirror, define the alignment fc-los reference axis nominally parallel to the ship centerline Y-plane. The ORU reference axis is established by navigation from a known angular relationship to the SINS.

The OAG optically measures the MBMA (Bdaim) of the GS when installed in the launch tube, and monitors any angular deviation arising from missile or from azimuth rate of change that may be induced by ship flexure. In addition, the OAG measures (in the deck plane) the MBMA [q(Bdaim)] due to the relative motion between the ORU and the reference PEAC that may be induced by ship flexure.

The OAG measures angle Bdaim using an analog servo-optics loop. A value of e(Bdaim) can be obtained independent of the OAG dynamic operation during coarse alignment. The value of e(Bdaim) for each of the 16 missiles is the missilized static value of the Bdaim resolver. The value of e(Bdaim), obtained from the 16 Bdaim resolvers, is used in the ALNSS during the simultaneous coarse alignment of all 16 missiles. In addition, the OAG for fine alignment has a single, separate loop for the measurement of the angle q(Bdaim). In all cases, the OAG equipment uses a closed-loop servo nulling technique. When a PEAC light beam is transmitted to a porro prism or to the ORU, and is not reflected parallel to itself, an MBMA exists. The PEAC and wedge drive assembly (WDA) combination tracks the light beam, and by servo loop techniques drives a pair of contrarotating wedges. The wedges on the PEAC table are interposed in the path of the light beam and function to position the reflected light beam in azimuth until parallel to the outgoing transmitted light beam, thereby achieving a PEAC nulled servo loop for q(Bdaim). A similar set of wedges at each station assembly permits the reflected light beam from the missile porro prism to be positioned parallel to the beam transmitted by either the port or starboard PEAC. The total angle through which the two light beams have been deviated by the wedges is the MBMA. The MBMA is equal to Bdaim plus q(Bdaim).

The OAG converts the angular optically measured values Bdaim (fig. 11-20) and q(Bdaim) (fig. 11-21) into the appropriate computed electrical signals. Bdaim and q(Bdaim) values obtained by the servo-optics loop are converted by resolver, connected to the contrarotating wedge drive shaft, into dynamic analog error signals. The error signals electrically represent the optically measured MBMA.

During fine alignment channelized operation, the OAG transmits computed analog error signals Bdaim and q(Bdaim) to the ALNSS via system switching for summation with other error signals. Only one missile at a time may be prepared by the OAG. The signals combined are a part of the ALNSS target bearing correction. Signal q(Bdaim) is used during the fine alignment phase only as part of the fine alignment of an individual missile on the next-to-fire basis. Signal Bdaim is used during the missilized coarse alignment as e(Bdaim) and when switched during the channelized fine alignment operations, becomes Bdaim.

## OAG EQUIPMENT

The OAG is comprised of specialized equipment which provide the necessary optical interfaces, controls, logic, and displays required to perform the preceding functions. The OAG consists of the following major components (shown in fig. 11-18):

1. 8 adjustable mount assemblies
2. 8 station assemblies
3. 1 PEAC table assembly
4. 1 Alignment Periscope Mk 52 Mod 4
5. 1 alignment control console assembly
6. 12 light tube assemblies

### Adjustable Mount Assembly

The adjustable mount assemblies provide the interface between the ship and the station assemblies (STAs). The adjustable mount assemblies are mounted rigidly to the foundation plate located between a pair of port and starboard (athwartship) missile launch tubes. The foundation plate is part of the ship spectacle plate, (fig. 11-18). The adjustable mount assembly is used to adjust and align the station assembly during installation or optical realignment procedures.

### Station Assembly

Four STAs are located port and four starboard of the ship centerline Y-plane. Each STA services a pair (one port, one starboard) of missiles. Each STA contains a station box, with two WEDAs and a manual input drive assembly. In use, the STA pentamirror assembly, as a part of the station box, may be indexed to direct an optical light beam from PEAC to the port side, to the starboard side, or to a see-thru position, in order to monitor the azimuth position of the porro prism of a GS. The see-thru position allows the light beam to pass through the open vee between the pair of mirrors forming two sides of the STA pentamirror, and on to subsequent STAs. Test position of the STA pentamirror is provided for installation and realignment purposes. In all cases, the STA pentamirror remains fixed until a command is received to reposition. A manual override is available to circumvent failure of automatic indexing. One WDA is mounted on the starboard side and the other on the port side of the station box. The WDA provides the drive mechanism to position the optical wedges and the output resolver. The PEAC light beam is reflected by an STA pentamirror assembly through the optical wedge to the porro prism on the GS. The porro prism (fig. 11-19) reflects the beam at an angle proportional to the missile misalignment bearing. The beam retraces the forward path through the optical wedges and the STA pentamirror back to the PEAC. The PEAC converts the position of the returning optical beam to an error signal proportional to the MBMA (Bdaim). The error signal drives the wedge drive servo motor, which contrarotates the wedges. The wedges will continue to rotate and deviate the transmitted and the reflected optical beam until the reflected optical beam is parallel with the input beam, and the error signal approaches zero. The angle through which the wedges rotate is proportional to the MBMA angle. A resolver mechanically coupled to the WDA also produces a dynamic analog signal proportional to the MBMA. The analog signal Bdaim is transmitted to the ALNSS via system switching for use during both coarse and fine alignment operations.

### PEAC Table Assembly

The PEAC table assembly is located on the aft or MC side of bulkhead 58. The PEAC table subassembly is that portion of the PEAC table assembly bolted and dowelled rigidly to the bulkhead. Three adjustable PEACs are mounted on the PEAC table subassembly, with their light beams directed inboard. All are aligned parallel to each other. The PEAC table subassembly also houses the three servo amplifier assemblies (SAMAs) that are used as part of the WDA servo loops. Associated with each PEAC is the table pentamirror assembly (TPA). The TPA pentamirrors can be automatically or manually indexed. The possible combination of indexing positions of the three TPA pentamirrors allows a given PEAC light beam to be directed along the port or starboard fc-los to the STA, or directed to the ORU mirror located in the navigation center (NC). A single WDA mounted on the PEAC table subassembly is associated with the reference PEAC. The WDA-PEAC combination permits continuous measurements of the relative motion of the ORU bearing misalignment angle induced by ship flexure. The WDA operation is part of the servo-optics loop for the dynamic measuring of the misalignment angle of the reference PEAC-to-ORU. The operation and function performed by the WDA on the PEAC table is identical to that of the WDA installed on each station box. The resolver output from the PEAC table WDA resolver and reference PEAC monitoring the ORU, produce a dynamic analog signal proportional to the MBMA (q(Bdaim)). Signal q(Bdaim) is transmitted (fig. 11-20) to the ALNSS via system switching for use during the fine alignment operation on the next-to-fire, missile-channelized basis.

In addition, redirecting either the port or starboard PEAC light beam permits either PEAC to service all 16 missiles without a reduction in firing rate for a casualty operation.

### Alignment Periscope

Alignment Periscope Mk 52 Mod 4 is an optical-mechanical assembly that translates the light beam fc-los horizontally and vertically from any PEAC to the ORU. The alignment periscope is mounted on the forward side of bulkhead 58.

Any change in the alignment of the reference PEAC to the upper ORU during a tactical condition is compensated for by the reference WDA.

The amount of compensation will be read off at the WDA resolver and then summed with the starboard or port PEAC WDA resolver reading to make up the MBMA used in the ALNSS.

### Alignment Control Console

The alignment control console (ACC) is a compartmentalized enclosure attached by shock mounts to the aft side of bulkhead 58.

In general, the ACC provides switching and controls for OAG optical equipment. The switching also provides the control for each STA and its port and starboard PEACs. Further, the switching provides the distribution of the 800-hertz reference to the output resolver of each WDA and the transmission of the output signal of each resolver to the MCC. STA control is enabled by STA switch which, in turn, is commanded by the missile control logic of the missile to be measured. The PEACs associated with their respective STA are provided with switching to enable a paralleling operation for a casualty condition. For examble, the starboard PEAC normally handles missile 1 through 8; for a casualty operation, however, the starboard PEAC can handle missiles 9 through 16. The switching of the PEAC switch provides that the pentamirror may be indexed so that either PEAC can handle the missiles normally associated with the other PEAC with no reduction in acquisition rates.

Additional functions of the ACC include:

1. Transmitting to the CDSS, the signals required by the FCS operators to determine the status of the OAG.
2. Providing for remote/tactical (MCC) or local (MC) control.

The following is a summary of the functions performed by the controls and indicators available at the ACC for use in local or MCC remote control.

When selected for remote operation, the ACC is controlled by the CDSS. In remote operation, the ACC provides the necessary actuator-indicator(s) (A/Is) to initiate the MCC and NORMAL TPA pentamirror function. In addition, the ACC provides the necessary display and controls to operate the OAG when commanded by the CDSS. The ACC controls and displays for SELECT and STATUS are located on the control display panel assembly (CDPA) panels, and are normally used in the remote operation.

Local operation of the ACC controls the operation of the OAG completely. The ACC provides all the A/Is, display, and controls necessary for the MC operator to perform all the required functions for local operation. All controls available for remote operation are available for local control.

### Light Tube Assembly

The OAG provides 12 open-ended, hollow, cylinderical light tube assemblies (LTAs). The entire length of each LTA encompasses the light beams of both the port and starboard PEACs from the PEAC table aft to the farthest STA. Each LTA is supported near each open end by a light tube support assembly. The ends of each LTA are secured to the successive spectacle plates of each pair of launch tubes. The LTAs are arranged to be mounted concentrically around the light beams and the aperture of each STA. The LTAs then span the gap between each STA in line with the PEAC los.

The LTAs are used to maintain a stabilized path for the transmission of the PEAC light beams when in a nonstowed or operating position.

## CAPABILITIES

Each STA is capable of measuring the missile MBMA (Bdaim) up to ±30 minutes of angle. For accuracy requirements, the MBMA (Bdaim) of the missile shall not exceed ±15 minutes of angle. Wedge angle rotation of ±30 minutes is available for missile onloading. Either the port or the starboard PEAC is capable of measuring the MBMA (Bdaim) at any 1 of the 16 missiles during a casualty operation without any reduction in firing rates.

The OAG, when assigned to tactical/remote control, is capable of transmitting a status indication to the CDSS indicating the status of the equipment. When operating in remote control, the ACC transmits a green OAG normal signal to the CDSS indicating that the following conditions exists in the OAG equipment:

1. Both port and starboard TPA pentamirrors have a normal report position (an alternative is either a port or a starboard casualty report of TPA pentamirror positions).
2. Reference PEAC's report of a wedge null.

During remote operation, the absence of either of the preceding conditions results in a red OAG not normal condition. In addition, the presence of green or white OAG normal signal at the CDSS panel indicates that the 28-volt d.c. system power is available at the OAG. When operating in LOCAL control, the ACC transmits an OAG normal signal. This is a white signal, denoting local control is selected. In the absence of either the remote or local OAG normal signal, a red OAG STATION REPORTS alarm is displayed on the control console in MCC.

The OAG is capable of supporting the firing of missiles while in a selected LOCAL control. This capability is available on an emergency basis only. Emergency procedures require that verbal communication be established between the MCC and the MC operators to assign the STA for proper sequencing of the selected missiles next to fire. The selection of the missile on the ACC by the OAG operator then provides the proper OAG ready signal status to the control console.

When operating in remote control, the ACC transmits to the CDSS an OAG ready signal indicating that the following conditions exist in the OAG equipment:

1. STATION switch(s) is positioned
2. STA pentamirror is positioned
3. STA wedge servo is nulled
4. STA pentamirror interference does not exist
5. No OAG hold

The absence of any of the conditions noted results in an OAG ready alarm condition. The OAG ready alarm signal is switched to the channel in operation.

## SYSTEM DESCRIPTION

The OAG is a subsystem of the FCS, and provides the ALNSS with the measurement of the misalignment of the missile reference bearing axis with respect to the ORU in the deck plane.

When the POSEIDON missile is initially placed in the launching tube, a small misalignment angle exists between the missile reference bearing axis of the GS and the fc-los. Another contributory factor to the MBMA is a slight movement of the missile after it is installed in the tube. These two conditions are static misalignments. The third condition, which is dynamic in nature, is the apparent MBMA induced by ship flexure. If all the contributing factors of the MBMA are not measured by the OAG and compensated for by the FCS prior to launching a missile, the missile will contain an uncompensated angular deviation error in azimuth or bearing. Various optical, electrical, and mechanical components of the OAG function to measure the angular deviation and to provide an analog output that represents the magnitude and polarity of the MBMA measurement when used for both the coarse and fine alignment phases. The MBMA, represented by the analog output, is transmitted to the ALNSS. A corrected azimuth gimbal torquer signal is generated by the ALNSS by combining the analog signals representing the target bearing, ownship heading, and relative missile bearing with the MBMA. The resulting signal represents the solution to the alignment problem for static or dynamic conditions as used in both the coarse and fine alignment phases. The optical components, which measure the missile MBMA relative to the fc-los include:

Two PEACS (one port, one starboard)
Two TPAs pentamirrors
Eight STAs (pentamirrors and optical wedges)
Sixteen missile porro prisms

In addition to the aforementioned optical components, there are components which measure the MBMA of the ORU relative to the fc-los; they are:

Alignment Periscope Mk 52 Mod 4
Reference PEAC
TPA pentamirror
Wedge drive and support assembly (optical wedges)
Optical reference unit

The measurement of the MBMA [q(Bdaim)] with respect to the ORU and the fc-los is accomplished in a manner similar to that described for the MBMA (Bdaim) measurement of the missile. The main difference is that the q(Bdaim) measurement is maintained by monitoring the forward directed PEAC light beam to the ORU; whereas, the MBMA (Bdaim) measurement is monitored by the aft-directed PEAC light beam to the porro prism. The MBMA [q(Bdaim)] measurement of the ORU, with respect to the reference PEAC, may be that which is induced by ship flexure. The polarity and magnitude of the MBMA (Bdaim) is produced by the resolver generating a computed analog signal and transmitting that signal to the ALNSS. The analog signal, which represents the q(Bdaim) MBMA, is combined with other signals in the ALNSS, and provides a dynamic bearing correction for use in the fine alignment phase. The OAG then provides the ALNSS with the required functional signals, which are used by the FCS in the solution of the alignment problem.

## DETAILED ANALYSIS (ELECTRO-OPTICAL)

The general functional analysis of the OAG electro-optical components has been incorporated into the physical description portion of this chapter. Thus, the text continuity provides in one area, not only a physical picture, but also presents a functional description of how the OAG equipment operates. In the following paragraphs, the electro-optical functions are more complex and the operational theory is presented primarily as background information so that the operator may better understand the function of the optics used in the OAG.

### Photoelectric Autocollimator Operational Theory

A photoelectric autocollimator (PEAC) is a precise optical instrument. It is used in conjunction with the WDA as a null-sensing device to measure the angular displacement of a reflecting surface. A PEAC automatically evaluates this angular displacement and provides an electrical output signal proportional to the displacement. Since the three PEACs in the OAG are identical in all cases, a description of the operation of one suffices for all.

The PEAC contains a series of optical components that enables it to do the following: generate a shaped beam of light; transmit this light to a remote reflector; receive this same reflected beam and analyze it with respect to the angular azimuth displacement between it and the transmitted beam; and provide electrical output signals related to the azimuth position of the reflector. These optical components also allow visual evaluation of the remote reflector position.

The shaped-light image is generated and transmitted in the following manner (fig. 11-22). The projected light beam is supplied by a 6.3-volt a.c. ribbon-filament, incandescent lamp. The filament emits uniform light intensity for the optical system. The optics are focused on the filament and the light passes to the condenser lens assembly, which contains two condenser lenses and an infrared absorbing filter. Passing through the first condenser lens, the light is collimated and transmitted to the infrared absorbing filter. This infrared absorbing filter absorbs the radiant heat from the lamp while transmitting a maximum amount of visible light energy. The heat is transferred to the condenser holder and to cooling air from a blower. The light then proceeds

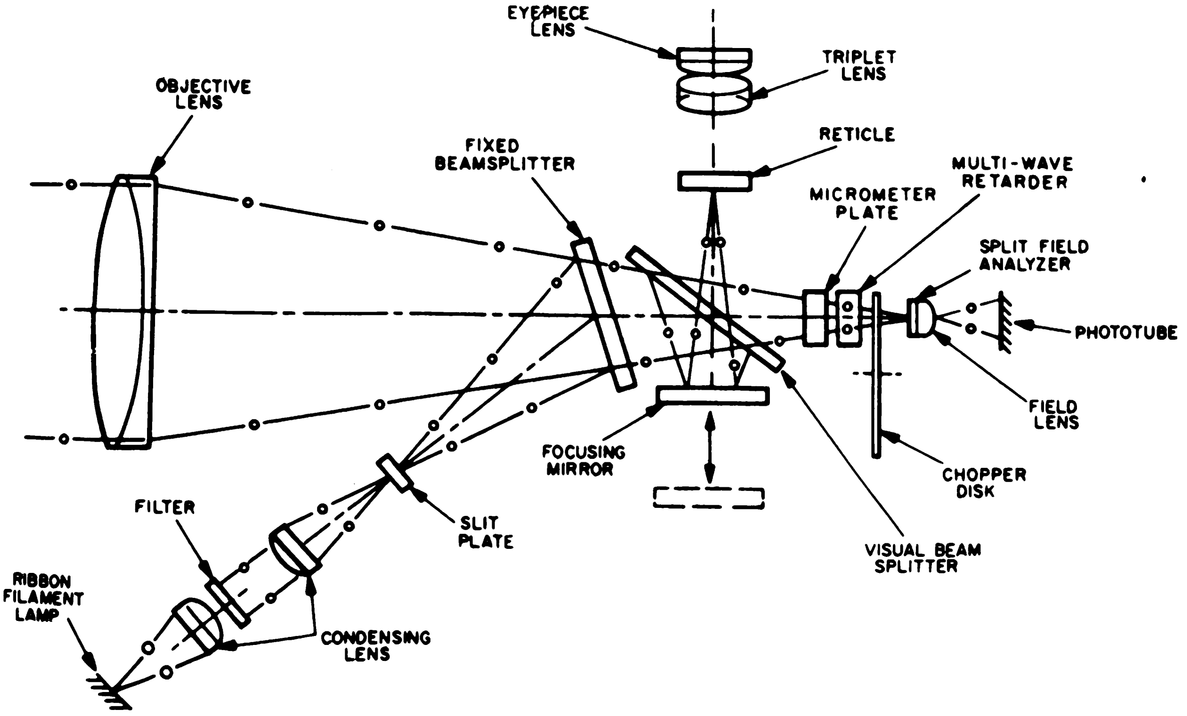

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Figure 11-22.—Photoelectric autocollimator optical schematic.

as collimated rays from the filter to the second condenser lens. This second condenser lens directs the light to the slit assembly and slit plate, bringing the beam to a focus at the back of the slit.

The slit occludes part of the light transmitted by the condenser lens to produce a sharp, clear, rectangular image of light about 0.10 inch in height and 0.01 inch in width. The slit is imaged at the focal point of the collimating lens and provides the secondary source of the PEAC light beam illumination. The size enlarges to about 3 inches in height and 0.30 inch in width as the collimated beam exits from the objective lens. Triangular pips, provided on the slit, are centered vertically on opposite sides of the image and function as a vertical reference for evaluating the slit image on the eyepiece reticle during visual operation.

Light leaving the slit assembly is incident on the partially silvered, fixed beamsplitter, which transmits and reflects light striking it. The beamsplitter is so positioned that it reflects part of the light to the objective lens. The remaining light is transmitted through the beamsplitter and absorbed by the black internal surfaces of the housing. The objective lens is a collimator, therefore the emerging light rays are parallel. This collimated light from the objective lens emerges from the PEAC and is transmitted to the remote reflector (porro prism or ORU mirror).

The remote reflector returns the light beam to the objective lens, which focuses the beam on the masked, split-field analyzer. This optical path extends from the objective lens through the fixed beamsplitter, the visual beamsplitter, the micrometer plate, the multiwave retarder, and the chopper disk. The partially silvered, visual beamsplitter diverts some of this returning light to an adjustable focusing mirror that in turn reflects the light to a reticle, which is observed through an eyepiece lens and a triplet lens assembly. Light transmitted through the visual beamsplitter passes through a micrometer plate, which permits fine azimuth adjustment of the returning light beam for centering the light beam on the split-field analyzer. For small angles of rotation of the micrometer plate, the resultant azimuth displacement of the image is proportional to the image displacement due to remote reflector azimuth deviation. The plate is adjusted by a micrometer screw and calibrated in seconds of azimuth angle of remote deviation. The micrometer control knob is graduated every second from 0 to 99, and numbered every 5 seconds from 0 to 95. The micrometer barrel has three graduations numbered 0, 100, and 200.

The multiwave retarder (depolarizer) in the PEAC makes the PEAC insensitive to the effects of any spurious polarization in the returning light beam. The removal of the polarization effect of the returning light beam ensures that all the light wave frequencies reach the rotating polarizing disk in a random fashion. The prime purpose of the multiwave retarder then is to depolarize the returning light beam by spreading the planes of polarization over all light wave frequencies. Polarization of the PEAC light beam may occur when the transmitted PEAC light beam is returned after being reflected from many surfaces used in the optical system. The depolarization of the returning light beam within the PEAC reduces the bias error to a negligible value. The returning light beam can become partially polarized or have a shift in the angle of polarization due to one or more of the following factors: (1) changes in the angular positions of the reflective surfaces; (2) changes in the number of reflective surfaces used; and/or (3) polarization of the optical components changing with changes in the internal stress. If any of the aforementioned occurs, there will be a change in the position of the polarization vector, which would cause an azimuth bias error independent of the automatic gain control (AGC). In addition to the bias error, there may exist a quadrature error that will cause a masking of the PEAC null. (The analysis of the change in the azimuth position of the polarization vector is beyond the scope of this text.) The multiwave retarder then serves to eliminate error caused by the polarization in the returning light beam by maintaining a d.c. bias, which varies only with light intensity and is compensated for by the AGC. The rotating chopper disk is a linear polarizer that is used to convert the light to a plane-polarized condition. The 400-hertz chopper motor drives the chopper disk at a synchronous speed of 200 revolutions per second (rps), orienting the plane of polarization with respect to a 400-hertz reference voltage. The phase of polarization is modulated at twice the speed of the disk or at 400 hertz. The split-field analyzer analyzes the plane-polarized, modulated light, and transmits it to the field lens. The split-field analyzer consists of two adjacent polaroid sections having mutually perpendicular axes of transmission. The returning light beam falls completely on either one section or the other, or on a combination of both, according to the magnitude of the deviation of the remote reflector. The field lens positions the returned light to the PEAC on the phototube; therefore, light transmitted by the split-field analyzer is spread by the field lens over a large area, ensuring the linear response of the phototube. The phototube converts the light energy from this input into electrical energy. The electrical output of the phototube is amplified and its phase angle is compared to the reference signal. The output of the phototube is two electrical error signals—a 400-hertz a.c. error signal and the d.c. component of this error signal. The 400-hertz error signal has an amplitude that is proportional to the remote reflector displacement, and a phase relationship (with respect to a 400-hertz reference voltage) that is indicative of the direction of reflector displacement. The d.c. voltage component of the error signal indicates that the reflected light is present in the PEAC and is being analyzed.

The amplitude of the 400-hertz error signal and the phase relationship between the reference voltage and the error signal are the result of the following events. The split-field analyzer consists of two physically adjacent portions of material that have mutually perpendicular axes of transmission. The reflected light image from the remote reflector falls completely within one of these portions or in varying combinations of both portions (fig. 11-23). The plane of polarization of the light image is rotated by the chopper disk. Therefore, the intensity of the light that reaches the phototube is sinusoidal; maximum when the plane of polarization is parallel to the transmission axis, and minimum when the plane of polarization is at right angles to the transmission axis. This occurs twice during each revolution of the disk.

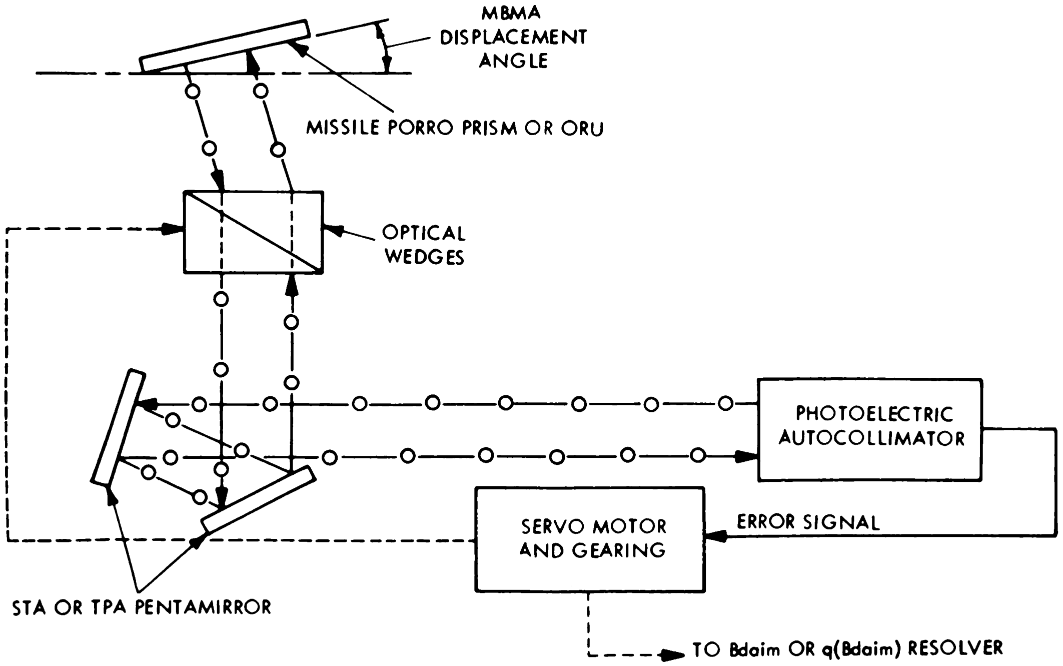

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Figure 11-23.—Optical wedge arrangement.

If the light falls on the split-field analyzer in the position shown in figure 11-24, view a, the phototube generates an electrical output proportional to the periodic intensity of the light. The phase relationship between output signal, view g, and the 400-hertz reference voltage is such that the output signal leads the 400-hertz reference voltage to 90°.

If the deviation of the remote reflector causes the beam to strike the analyzer as shown in view b, output signal, view h, has the same amplitude as the signal shown in view g; however, there is a phase difference of 180° between the two and, therefore, a phase difference of 90° (signal lagging) between the signal in view h and the reference voltage.

Similar results are obtained when the beam strikes the analyzer in the areas shown in views c and d. The resultant voltage curves, shown in views i and j, exhibit the same phase differences (with respect to the reference voltage) as the curves shown in views g and h. The amplitudes of the resultants in views i and j are dependent upon the amplitudes of the wave components transmitted simultaneously by the horizontal and vertical sections of the analyzer.

If the light is incident on the center of the analyzer as shown in view e, the horizontal and vertical components of the emergent light will have equal and opposing amplitudes; therefore, the flux intensity incident on the phototube is constant non-a.c. voltage output as shown in view k.

As previously stated, the d.c. component of the phototube output indicates that the reflected light image from the remote reflector is incident on the split-field analyzer. This d.c. output is dependent upon the intensity of the light striking the phototube. Servo error circuits provide this signal with an automatic gain control (agc) feature to maintain its amplitude at a constant level regardless of decreasing phototube sensitivity and light attentuation caused by varying light transmission.

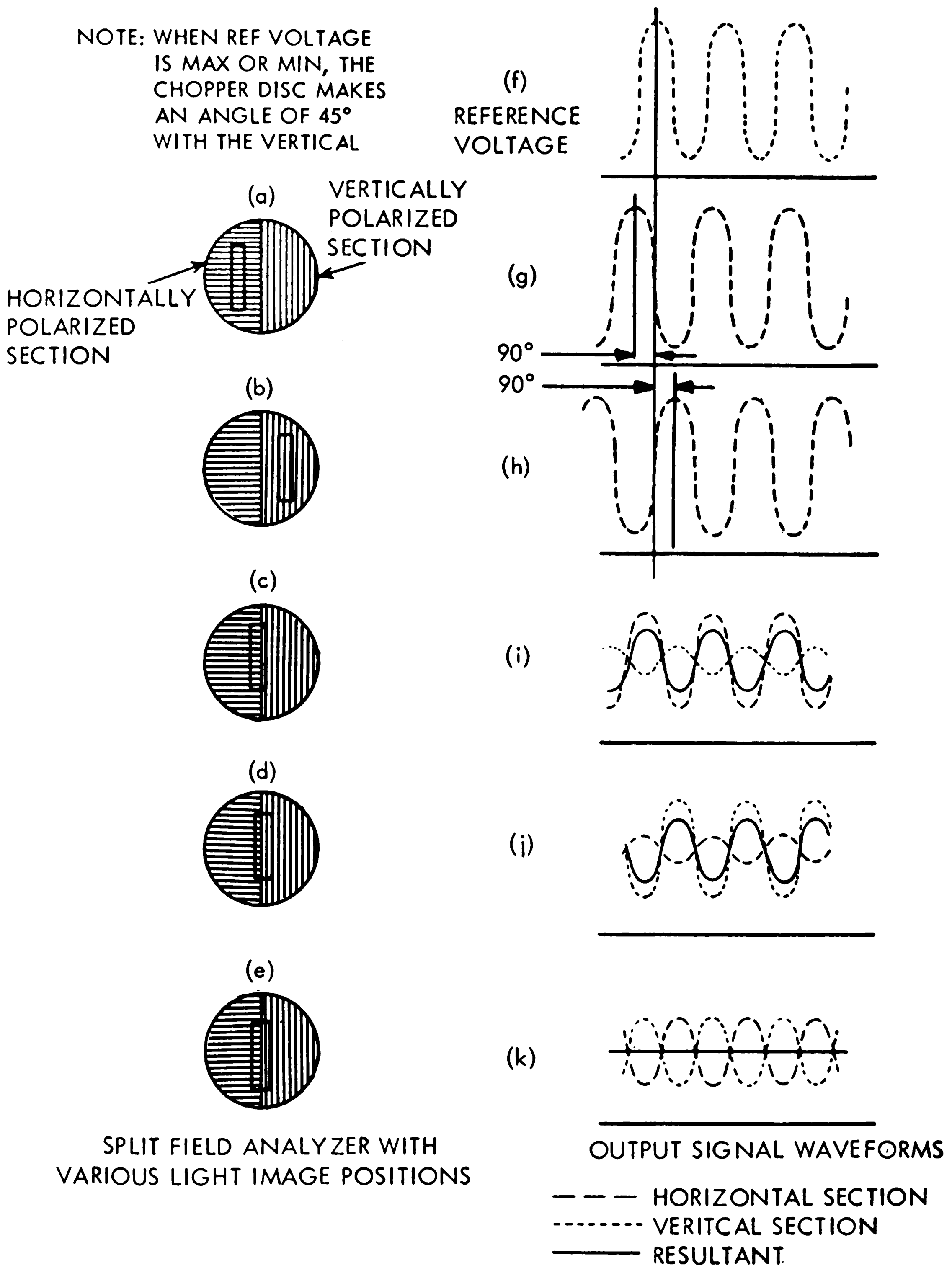

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Figure 11-24.—PEAC output signals.

### Wedge Drive Assembly Operational Theory

The optical wedges in the WDA are situated in the optical los of the light beam from the PEAC and the reflected light beam from the missile porro prism or the ORU cube. The wedges deviate the azimuth relationship of light beams incident upon them. When the reflected light is not parallel with the incident light, a servo motor is driven by the a.c. error signal provided by the PEAC. The servo motor rotates each wedge in opposite directions, varying the physical relationship between the surfaces and the refractive relationships between the light beams until the outgoing and incoming light beams appear parallel. The error signal from the PEAC is now zero and the wedge drive servo motor is stopped.

When the optical wedges are in this position of zero error, the transmitted beams entering and leaving the wedges are not parallel to each other. The same condition holds true for the reflected beam; however, the wedges have been turned so that their refractive qualities cause the portions of the transmitted beam and the reflected beam lying between the PEAC and the STA WDA or the PEAC table WDA to be parallel. The incident and reflected light beams from a WDA to a porro prism/ORU are also parallel and coincident. The Bdaim and q(Bdaim) resolvers are rotated through the same distance as the wedges by a mutually driven gear train; therefore, the OAG error signals Bdaim and q(Bdaim) are a function of the wedge rotation angle. Bdaim and q(Bdaim) are established by the following equation:

$$\text{Bdaim or q(Bdaim)} = 2D \sin R$$

Where R represents the wedge rotation angle in degrees, and D equals 1206 arc-seconds.

## OAG SUMMARY

This section should be used as an introduction to optics and the optical alignment group. For further technical information, you should refer to NAVORD OP 3587, and OP 3804, and OD 42376.

Evolutions and emergency procedures involving the optical alignment group and the Fire Control System in general can be found in the operating manuals. These manuals are divided into PSs, WPs, and CPs, which are to be strictly adheared to in carrying out any evolution or procedure. This set of manuals is NAVORD OD 43144.

CHAPTER 12 (PAGES 252 THROUGH 264) HAS BEEN DELETED FROM THIS EDITION.

## APPENDIX I

# THE METRIC SYSTEM

The metric system was developed by French scientists in 1790 and was specifically designed to be an easily used system of weights and measures to benefit science, industry, and commerce. The metric system is calculated entirely in powers of 10, so one need not work with the various mathematical bases used with the English system, such as 12 inches to a foot, 3 feet to a yard, and 5280 feet to a mile.

The system is based on the "meter" which is one ten-millionth of the distance from the Equator to the North Pole. It is possible to develop worldwide standards from this base of measurement. The metric system of weights is based on the gram, which is the weight of a specific quantity of water.

Soon after the system was developed scientists over the world adopted it and were able to deal with the mathematics of their experiments more easily. The data and particulars of their work could be understood by other scientists anywhere in the world. During the early 19th century many European nations adopted the new system for engineering and commerce. It was possible for these countries to trade manufactured goods with one another without worrying whether it would be possible to repair machinery from another country without also buying special wrenches and measuring tools. Countries could buy and sell machine tools and other sophisticated and precision machinery without troublesome modifications or alterations. It was much easier to teach the metric system, since meters can be changed to kilometers or centimeters with the movement of a decimal point, which is roughly like being able to convert yards to miles or inches by adding zeros and a decimal instead of multiplying by 1760 or dividing by 36.

With the exception of the United States, all the industrialized nations of the world have adopted the metric system. Even England and Canada are changing from their traditional systems of measure, and the metric system will be almost universal by 1980.

Although the metric system has not been officially legislated by the Congress, the metric system is becoming more prominent in this country. Most automobile mechanics own some metric wrenches to work on foreign cars or foreign components in American cars. Almost all photographic equipment is built to metric standards. Chemicals and drugs are usually sold in metric quantities, and "calorie counters" are using a metric unit of thermal energy.

Because we are allied with countries who use the metric system, much of our military information is in metric terms. Military maps use meters and kilometers instead of miles, and many weapons are in metric sizes, such as 7.62 mm, 20 mm, 40 mm, 75 mm, and 155 mm. Interchange of military equipment has caused a mixture of metric and English measure equipment since World War I when the army adopted the French 75 mm field gun, and World War II when the Navy procured the Swedish 40 mm Bofors and the Swiss 20 mm Oerlikon heavy machine guns.

It is inevitable that the United States will officially adopt the metric system. Exactly when this happens and how rapidly the changeover will depend on economics, since the expense of retooling our industry and commerce to new measurements will be very great. The cost of conversion will be offset by increased earnings from selling machinery and products overseas. Another benefit is that scientists use the metric system, but their calculations now have to be translated into English measure to be used by industry. With adoption of the metric system ideas can go directly from the drawing board to the assembly line.

The Navy will be using the metric system more during the next few years. Although you will find it easier to solve problems using this system, at first you will find it difficult to visualize or to estimate quantities in unfamiliar units of measure.

Fortunately, many metric units can be related to equivalent units in the English system.

The meter which is the basic unit is approximately one-tenth longer than a yard.

The basic unit of volume, the liter, is approximately one quart. The gram is the weight of a cubic centimeter, or milliliter, of pure water and is the basic unit of weight. As a common weight though, the kilogram, or kilo, which equals the weight of a liter of water, weighs 2.2 pounds. The cubic centimeter (cc) is used where we would use the square inch, and where we measure by the fluid ounce, the metric system employs the milliliter (ml). For power measure the metric system uses the kilowatt (kW), which is approximately 1.3 horsepower.

In terms of distance, a land mile is eight-fifths of a kilometer and a nautical mile is 1.852 kilometers, or nearly 2 kilometers.

A basic metric expression of pressure is the kilogram per square centimeter, which is 14.2 psi, nearly 1 atmosphere of pressure.

When working on foreign machinery, you may notice that your half-inch, three-quarter inch, and one-inch wrenches will fit many of the bolts. These sizes correspond to 13 mm, 19 mm, and 26 mm respectively in the metric system, and are very popular because they are interchangeable. The 13/16-inch spark plug wrench, which is standard in this country, is intended to fit a 20 mm nut.

The basic quantities of the metric system are multiplied or divided by powers of 10 to give other workable values. We cannot easily measure machine parts in terms of a meter, so the millimeter, or one-thousandth of a meter is used. For very fine measure the micron, also called the micrometer, can be used. It is one-millionth part of a meter, or one-thousandth of a millimeter. For small weights the milligram, one-thousandth of a gram is used. All of these multiples are expressed with standard prefixes taken from Latin:

micro = 1/1,000,000
milli = 1/1,000
centi = 1/100
*deci = 1/10
*deca = 10
*hecto = 100
kilo = 1,000
*myria = 10,000
mega = 1,000,000

* Rarely used

Over the next few years the metric system will become more used by the Navy as well as by the civilian world. You will find it easy to work with once you have mastered the basic terms. It will be difficult to translate values from our present system to the metric system, but this operation will become unnecessary once the new measurements are totally adopted.

Tables of equivalent English measure and metric equivalents are essential when you work simultaneously with both systems. The table which follows shows the equivalent measures of the two systems. The columns on the left have the equivalent values which are accurate enough for most work, and on the right are the multiples used to convert the values with a high degree of accuracy.

# U.S. CUSTOMARY AND METRIC SYSTEM UNITS OF MEASUREMENTS

## THESE PREFIXES MAY BE APPLIED TO ALL SI UNITS

| Multiples and Submultiples | Prefixes | Symbols |
|---|---|---|
| 1 000 000 000 000 = $10^{12}$ | tera (tĕr'ȧ) | T |
| 1 000 000 000 = $10^{9}$ | giga (jĭ'gȧ) | G |
| 1 000 000 = $10^{6}$ | mega (mĕg'ȧ) | M ● |
| 1 000 = $10^{3}$ | kilo (kĭl'ō) | k ● |
| 100 = $10^{2}$ | hecto (hĕk'tō) | h |
| 10 = 10 | deka (dĕk'ȧ) | da |
| 0.1 = $10^{-1}$ | deci (dĕs'ĭ) | d |
| 0.01 = $10^{-2}$ | centi (sĕn'tĭ) | c ● |
| 0.001 = $10^{-3}$ | milli (mĭl'ĭ) | m ● |
| 0.000 001 = $10^{-6}$ | micro (mī'krō) | μ ● |
| 0.000 000 001 = $10^{-9}$ | nano (năn'ō) | n |
| 0.000 000 000 001 = $10^{-12}$ | pico (pē'kō) | p |
| 0.000 000 000 000 001 = $10^{-15}$ | femto (fĕm'tō) | f |
| 0.000 000 000 000 000 001 = $10^{-18}$ | atto (ăt'tō) | a |

● MOST COMMONLY USED

| Multiply | By | To Obtain |
|---|---|---|
| Acres | 40.47 | Ares |
| Acres | 4,047 | Centares |
| Acres | 10 | Square chains |
| Acres | 43,560 | Square Feet |
| Acres | 4,840 | Square Yards |
| Ares | 0.02471 | Acres |
| Ares | 100 | Centares |
| Ares | 1,076 | Square Feet |
| Ares | 119.6 | Square Yards |
| Barrels (U.S., dry) | 3.281 | Bushels |
| Barrels (U.S., liquid) | 4.21 | Cubic Feet |
| Barrels (U.S., liquid) | 31.5 | Gallons |
| Board Feet (1' x 1' x 1') | 144 | Cubic inches |
| Cable lengths (U.S.) | 120 | Fathoms |
| Cable lengths (U.S.) | 720 | Feet |
| Cable lengths (U.S.) | 240 | Yards |
| Centares | 10.76 | Square feet |
| Centares | 1.196 | Square Yards |
| Centimeters | 0.3937 | Inches |
| Cubic Centimeters | 0.06102 | Cubic Inches |
| Chains | 66 | Feet |
| Chains | 100 | Links |
| Chains | 4 | Rods |
| Cubic Feet | 1,728 | Cubic Inches |
| Cubic Feet | 0.02832 | Cubic Meters |
| Cubic Feet | 0.03704 | Cubic Yards |
| Cubic Feet | 6.229 | Gallons (British) |
| Cubic Feet | 7.481 | Gallons (U.S.) |
| Cubic Feet | 28.316 | Liters |
| Cubic Inches | 16.39 | Cubic Centimeters |
| Cubic Inches | 0.0005787 | Cubic Feet |
| Cubic Inches | 0.003606 | Gallons (British) |
| Cubic Inches | 0.004329 | Gallons (U.S.) |
| Cubic Inches | 0.01639 | Liters |
| Cubic Meters | 35.31 | Cubic Feet |
| Cubic Meters | 1.308 | Cubic Yards |
| Cubic Yards | 27 | Cubic Feet |
| Cubic Yards | 0.7646 | Cubic Meters |
| Cubic Yards | 764.6 | Liters |
| Degrees (C.)+ 17.8 | 1.8 | Degrees (F.) |
| Degrees (F.) −32 | 0.5556 | Degrees (C.) |
| Degrees | 0.01745 | Radians |
| Fathoms | 0.00833 | Cable Lengths (U. S.) |
| Fathoms | 6 | Feet |
| Fathoms | 1.8288 | Meters |
| Feet | 30.48 | Centimeters |
| Feet | 0.1667 | Fathoms |
| Feet | 0.3048 | Meters |
| Feet per Minute | 0.01136 | Miles per Hour |
| Feet per Second | 0.5921 | Knots |
| Feet per Second | 18.288 | Meters per Minute |
| Feet per Second | 0.6818 | Miles per Hour |
| Furlongs | 10 | Chains |
| Furlongs | 660 | Feet |
| Furlongs | 40 | Rods |
| Furlongs | 220 | Yards |
| Gallons (British) | 4,546.1 | Cubic Centimeters |
| Gallons (British) | 0.1605 | Cubic Feet |
| Gallons (British) | 277.274 | Cubic Inches |
| Gallons (British) | 1.2009 | Gallons (U.S.) |
| Gallons (British) | 4.546 | Liters |
| Gallons (British) | 4 | Quarts (British) |
| Gallons (U.S.) | 0.03175 | Barrels (liquid, U.S.) |
| Gallons (U.S.) | 3,785.4 | Cubic Centimeters |
| Gallons (U.S.) | 0.13368 | Cubic Feet |
| Gallons (U.S.) | 231 | Cubic Inches |
| Gallons (U.S.) | 0.8327 | Gallons (British) |
| Gallons (U.S.) | 3.785 | Liters |
| Gallons (U.S.) | 4 | Quarts (U.S.) |
| Grams | 15.43 | Grains |
| Grams | 0.001 | Kilograms |
| Grams | 1,000 | Milligrams |
| Grams | 0.03527 | Ounces (avoirdupois) |
| Hands | 10.16 | Centimeters |
| Hands | 4 | Inches |
| Hectares | 2.471 | Acres |
| Hectares | 100 | Ares |
| Hectoliters | 0.1 | Cubic Meters |
| Hectoliters | 26.417 | Gallons (U.S.) |
| Hectoliters | 100 | Liters |
| Hogsheads | 2 | Barrels (Liquid, U.S.) |
| Hogsheads (U.S.) | 63 | Gallons (U.S.) |
| Hundredweights | 0.508 | Quintals (metric) |
| Inches | 72 | Points |
| Inches | 6 | Picas |
| Inches | 6 | Ems |
| Inches | 12 | Ens |
| Inches | 2.54 | Centimeters |

# Appendix I—THE METRIC SYSTEM

| Multiply | By | To Obtain |
|---|---|---|
| Inches | 0.0833 | Feet |
| Inches | 1,000 | Mils |
| Inches | 0.0277 | Yards |
| Inches of Mercury | 0.49131 | Pounds per Square Inch |
| Kilograms | 1,000 | Grams |
| Kilograms | 2.2046 | Pounds (Avoirdupois) |
| Kiloliters | 1 | Cubic Meters |
| Kiloliters | 1.308 | Cubic Yards |
| Kiloliters | 264.18 | Gallons (U.S.) |
| Kiloliters | 1,000 | Liters |
| Kilometers | 4.557 | Cable Lengths |
| Kilometers | 3,280.8 | Feet |
| Kilometers | 39,370 | Inches |
| Kilometers | 1,000 | Meters |
| Kilometers | 0.5396 | Miles, Nautical |
| Kilometers | 0.62137 | Miles, Statute |
| Kilometers | 1,093.6 | Yards |
| Knots | 1.1516 | Statute Miles per Hour |
| Knots | 1.688 | Feet per Second |
| Leagues, Nautical | 25.33 | Cable Lengths |
| Leagues, Nautical | 5.5597 | Kilometers |
| Leagues, Nautical | 3 | Miles, Nautical |
| Leagues, Statute | 4.8280 | Kilometers |
| Leagues, Statute | 3 | Miles, Statute |
| Links | 7.92 | Inches |
| Liters | 1,000 | Cubic Centimeters |
| Liters | 61.025 | Cubic Inches |
| Liters | 0.21998 | Gallons (British) |
| Liters | 0.26418 | Gallons (U.S.) |
| Liters | 0.8799 | Quarts (British) |
| Liters | 0.908 | Quarts (U.S., dry) |
| Liters | 1.0567 | Quarts (Liquid, U.S.) |
| Meters | 100 | Centimeters |
| Meters | 0.001 | Kilometers |
| Meters | 1.0936 | Yards |
| Meters | 3.281 | Feet |
| Meters | 39.37 | Inches |
| Meters | 1,000 | Millimeters |
| Meters | 1.0936 | Yards |
| Meters per Minute | 0.0547 | Feet per Second |
| Meters per Second | 2.237 | Miles per Hour |
| Microns | 0.001 | Millimeters |
| Miles, Nautical | 8.44 | Cable Lengths |

| Multiply | By | To Obtain |
|---|---|---|
| Miles, Nautical | 6,076.1 | Feet |
| Miles, Nautical | 72,963 | Inches |
| Miles, Nautical | 1.8532 | Kilometers |
| Miles, Nautical | 1,853.2 | Meters |
| Miles, Nautical | 1.1508 | Miles, Statute |
| Miles, Nautical | 1 | Minutes of Latitude |
| Miles, Nautical | 2,026.8 | Yards |
| Miles per Hour (Statute) | 88 | Feet per Minute |
| Miles per Hour (Statute) | 1.467 | Feet per Second |
| Miles per Hour | 0.8684 | Knots |
| Miles, Statute | 7.33 | Cable Lengths |
| Miles, Statute | 5,280 | Feet |
| Miles, Statute | 8 | Furlongs |
| Miles, Statute | 63,360 | Inches |
| Miles, Statute | 1.6093 | Kilometers |
| Miles, Statute | 1,609.3 | Meters |
| Miles, Statute | 0.8689 | Miles, Nautical |
| Miles, Statute | 1,760 | Yards |
| Millier (See Tons – Metric) | | |
| Milliradians | 206.265 | Seconds of Arc |
| Mils | 0.001 | Inches |
| Myriameters | 10 | Kilometers |
| Ounces (avoirdupois) | 28.3495 | Grams |
| Pint (Liquid, U.S.) | 4 | Gills (U.S.) |
| Pint (Liquid, Br.) | 4 | Gills (British) |
| Pint (Liquid, Br.) | 0.56825 | Liters |
| Pint (Liquid, U.S.) | 0.4732 | Liters |
| Pounds (avoirdupois) | 7,000 | Grains |
| Pounds (avoirdupois) | 453.59 | Grams |
| Pounds (avoirdupois) | 0.4536 | Kilograms |
| Pounds (avoirdupois) | 16 | Ounces |
| Pounds (avoirdupois) | 1.2153 | Pounds (troy) |
| Pounds (troy) | 0.8229 | Pounds (avoirdupois) |
| Pounds per Square Inch | 2.03537 | Inches of Mercury |
| Quart (British) | 1.1365 | Liters |
| Quart (British) | 2 | Pints (British) |
| Quart (Liquid, U.S.) | 0.9463 | Liters |
| Quart (U.S.) | 2 | Pints (U.S.) |
| Quintals (Metric) | 1.97 | Hundredweights |
| Quintals (Metric) | 100 | Kilograms |

| Multiply | By | To Obtain |
|---|---|---|
| Radians | 57.30 | Degrees |
| Rods | 16.3 | Feet |
| Rods | 25 | Links |
| Square Centimeters | 0.1550 | Square Inches |
| Square Feet | 0.0929 | Centares |
| Square Feet | 929 | Square Centimeters |
| Square Feet | 144 | Square Inches |
| Square Feet | 0.1111 | Square Yards |
| Square Inches | 6.452 | Square Centimeters |
| Square Inches | 0.006944 | Square Feet |
| Square Kilometers | 100 | Hectares |
| Square Kilometers | 0.3861 | Square Miles (Statute) |
| Square Meters (See Centares) | | |
| Square Miles, Statute | 640 | Acres |
| Square Miles, Statute | 25,900 | Ares |
| Square Miles, Statute | 259 | Hectares |
| Square Miles, Statute | 2.59 | Square Kilometers |
| Square Yards | 0.8362 | Centares |
| Square Yards | 9 | Square Feet |
| Square Yards | 1,296 | Square Inches |
| Tons (Long) | 1.016 | Metric Tons |
| Tons (Long) | 2,240 | Pounds (Avoirdupois) |
| Tons (Metric) (Millier) | 1,000 | Kilograms |
| Tons (Metric) (Millier) | 2,204.6 | Pounds (Avoirdupois) |
| Tons (Short) | 0.9072 | Metric Tons |
| Tons (Short) | 2,000 | Pounds (Avoirdupois) |
| Yards | 91.44 | Centimeters |
| Yards | 0.9144 | Meters |

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# FIRE CONTROL TECHNICIAN B 3&2, VOLUME 1

## NAVEDTRA 10211-B1

Prepared by the Naval Education and Training Program Development
Center, Pensacola, Florida

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Your NRCC contains a set of assignments and perforated answer sheets. The Rate Training Manual, Fire Control Technician B 3 & 2, Volume 1, NAVEDTRA 10211-B1, VOL. 1, is your textbook for the NRCC. If an errata sheet comes with the NRCC, make all indicated changes or corrections. Do not change or correct the textbook or assignments in any other way.

### HOW TO COMPLETE THIS COURSE SUCCESSFULLY

Study the textbook pages given at the beginning of each assignment before trying to answer the items. Pay attention to tables and illustrations as they contain a lot of information. Making your own drawings can help you understand the subject matter. Also, read the learning objectives that precede the sets of items. The learning objectives and items are based on the subject matter or study material in the textbook. The objectives tell you what you should be able to do by studying assigned textual material and answering the items.

At this point you should be ready to answer the items in the assignment. Read each item carefully. Select the BEST ANSWER for each item, consulting your textbook when necessary. Be sure to select the BEST ANSWER from the subject matter in the textbook. You may discuss difficult points in the course with others. However, the answer you select must be your own. Remove a perforated answer sheet from the back of this text, write in the proper assignment number, and enter your answer for each item.

Your NRCC will be administered by your command or, in the case of small commands, by the Naval Education and Training Program Development Center. No matter who administers your course you can complete it successfully by earning a 3.2 for each assignment. The unit breakdown of the course, if any, is shown later under Naval Reserve Retirement Credit.

### WHEN YOUR COURSE IS ADMINISTERED BY LOCAL COMMAND

As soon as you have finished an assignment, submit the completed answer sheet to the officer designated to grade it. The graded answer sheet will not be returned to you.

If you are completing this NRCC to become eligible to take the fleetwide advancement examination, follow a schedule that will enable you to complete all assignments in time. Your schedule should call for the completion of at least one assignment per month.

Although you complete the course successfully, the Naval Education and Training Program Development Center will not issue you a letter of satisfactory completion. Your command will make an entry in your service record, giving you credit for your work.

### WHEN YOUR COURSE IS ADMINISTERED BY THE NAVAL EDUCATION AND TRAINING PROGRAM DEVELOPMENT CENTER

After finishing an assignment, go on to the next. Retain each completed answer sheet until you finish all the assignments in a unit (or in the course if it is not divided into units). Using the envelopes provided, mail your completed answer sheets to the Naval Education and Training Program Development Center where they will be graded and the score recorded. Make sure all blanks at the top of each answer sheet are filled in. Unless you furnish all the information required, it will be impossible to give you credit for your work. The graded answer sheets will not be returned.

The Naval Education and Training Program Development Center will issue a letter of satisfactory completion to certify successful completion of the course (or a creditable unit of the course). To receive a course-completion letter, follow the directions given on the course-completion form in the back of this NRCC.

You may keep the textbook and assignments for this course. Return them only in the event you disenroll from the course or otherwise fail to complete the course. Directions for returning the textbook and assignments are given on the book-return form in the back of this NRCC.

mail your self-scored answer sheets to the Naval Education and Training Program Development Center where the scores will be verified and recorded. Make sure all blanks at the top of each answer sheet are filled in. Unless you furnish all the information required, it will be impossible to give you credit for your work. You may wish to record your scores on the assignments since the self-scoring answer sheets are not returned.

The Naval Education and Training Program Development Center will issue a letter of satisfactory completion to certify successful completion of the course (or a creditable unit of the course). To receive a course-completion letter, follow the directions given on the course-completion form in the back of this NRCC.

## PREPARING FOR YOUR ADVANCEMENT EXAMINATION

Your examination for advancement is based on the Manual of Navy Enlisted Manpower and Personnel Classification and Occupational Standards (NAVPERS 18068-D). The sources of questions in this examination are given in the Bibliography for Advancement Study (NAVEDTRA 10052). Since your NRCC and textbook are among the sources listed in this bibliography, be sure to study both in preparing to take your advancement examination. The standards for your rating may have changed since your course and textbook were printed, so refer to the latest editions of NAVPERS 18068-D and NAVEDTRA 10052.

## NAVAL RESERVE RETIREMENT CREDIT

The course is evaluated at 10 Naval Reserve retirement points, which will be credited upon satisfactory completion of the entire course. These points are creditable to personnel eligible to receive them under current directives governing retirement of Naval Reserve personnel. Naval Reserve retirement credit will not be given for this course if the student has previously received retirement credit for any Fire Control Technician B, NRCC or ECC.

## COMPREHENSIVE COURSE OBJECTIVE

The basic objective of this course (RTM/NRCC package) is to help the individual student meet the professional (technical) qualifications for advancement to Fire Control Technician B (ballistic missile) 3 and 2. By completing this course satisfactorily, and working conscientiously toward achieving the basic objective, the student will acquire much of the knowledge needed by a member of the FBM weapons team to:

1. interpret electrical, electronic, and fire control principles as they are applied in the POSEIDON Fire Control System.
2. operate, test, repair, and maintain equipment of the POSEIDON Fire Control System as typically performed by third and second class Fire Control Technicians, under supervision.

While working on this nonresident career course, you may refer freely to the text. You may seek advice and instruction from others on problems arising in the course, but the solutions submitted must be the result of your own work and decisions. You are prohibited from referring to or copying the solutions of others, or giving completed solutions to anyone else taking the same course.

Naval courses may include a variety of questions -- multiple-choice, true-false, matching, etc. The questions are not grouped by type; regardless of type, they are presented in the same general sequence as the textbook material upon which they are based. This presentation is designed to preserve continuity of thought, permitting step-by-step development of ideas. Some courses use many types of questions, others only a few. The student can readily identify the type of each question (and the action required) through inspection of the samples given below.

## MULTIPLE-CHOICE QUESTIONS

Each question contains several alternatives, one of which provides the best answer to the question. Select the best alternative, and blacken the appropriate box on the answer sheet.

### SAMPLE

s-1. The first person to be appointed Secretary of Defense under the National Security Act of 1947 was
1. George Marshall
2. James Forrestal
3. Chester Nimitz
4. William Halsey

Indicate in this way on the answer sheet:

| | 1 T | 2 F | 3 | 4 | |
|---|---|---|---|---|---|
| s-1 | ☐ | ■ | ☐ | ☐ | ___ |

## TRUE-FALSE QUESTIONS

Mark each statement true or false as indicated below. If any part of the statement is false the statement is to be considered false. Make the decision, and blacken the appropriate box on the answer sheet.

### SAMPLE

s-2. Any naval officer is authorized to correspond officially with any systems command of the Department of the Navy without his commanding officer's endorsement.

Indicate in this way on the answer sheet:

| | 1 T | 2 F | 3 | 4 | |
|---|---|---|---|---|---|
| s-2 | ☐ | ■ | ☐ | ☐ | ___ |

## MATCHING QUESTIONS

Each set of questions consists of two columns, each listing words, phrases or sentences. The task is to select the item in column B which is the best match for the item in column A that is being considered. Items in column B may be used once, more than once, or not at all. Specific instructions are given with each set of questions. Select the numbers identifying the answers and blacken the appropriate boxes on the answer sheet.

### SAMPLE

In questions s-3 through s-6, match the name of the shipboard officer in column A by selecting from column B the name of the department in which the officer functions.

| A | B |
|---|---|
| s-3. Damage Control Assistant | 1. Operations Department |
| s-4. CIC Officer | 2. Engineering Department |
| s-5. Disbursing Officer | 3. Supply Department |
| s-6. Communications Officer | |

Indicate in this way on the answer sheet:

| | 1 T | 2 F | 3 | 4 | |
|---|---|---|---|---|---|
| s-3 | ☐ | ■ | ☐ | ☐ | ___ |
| s-4 | ■ | ☐ | ☐ | ☐ | ___ |
| s-5 | ☐ | ☐ | ■ | ☐ | ___ |
| s-6 | ■ | ☐ | ☐ | ☐ | ___ |

ASSIGNMENTS 1 AND 2 (PAGES 2 THROUGH 12)
HAVE BEEN DELETED FROM THIS EDITION.

# Assignment 3

Analog Electromechanical Data Sensors; Servomechanisms

Textbook Assignment: Fire Control Technician (B) 3&2, Vol. 1, NAVEDTRA 10211-B1; pages 38-62

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*Learning Objective: Analyze the methods of representing and converting data within transmission systems.*

For items 3-1 and 3-2, refer to figure 4-1 of your textbook. A YES is indicated when the lamp in the secondary circuit of the transformer is lighted, and a NO is indicated when the lamp is out.

3-1. In the simple transmission circuit, what is the only possible YES and NO sequence that can be sent from place to place?

1. YES-NO-NO-YES
2. NO-YES-YES-NO
3. NO-NO-YES-YES
4. YES-NO-YES-NO

3-2. The circuit can be used to transmit numerical data, such as distance in feet. If one YES is equal to 5 feet, what total number of times must the switch be closed and then opened to transmit the distance of 20 feet?

1. 8
2. 2
3. 10
4. 4

Use the following alternatives for items 3-3 and 3-4:

1. Vector quantity
2. Scalar quantity
3. Resolved quantity
4. Separate quantity

3-3. What transmitted data can be completely described by a single numerical value?

3-4. What data must be described by two separate values?

3-5. In most data transmission systems, a vector quantity is transmitted by using

1. two separate vector quantities
2. two separate scalar quantities
3. a vector quantity and a scalar quantity
4. a scalar quantity and a directional quantity

*Learning Objective: Analyze the basic operation of analog data sensors.*

3-6. Most data sensors are classed as what type of device?

1. Analog
2. Preset
3. Digital
4. Directing

3-7. Which of the following characteristics best describes the action of a data sensor?

1. The input is mechanical and the output is mechanical
2. The input is electrical and the output is electrical
3. The input is mechanical and the output is electrical and mechanical
4. The input is mechanical or electrical and the output is mechanical or electrical

*Learning Objective: Analyze the functional operation of synchros and resolvers and recognize associated troubleshooting aids.*

3-8. Basic synchro torque indicating systems are comprised of a/an

1. rotor and stator
2. armature and field
3. transmitter and receiver
4. differential synchro and control transformer

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4. YES-NO-YES-NO

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3. The input is mechanical and the output is electrical and mechanical
4. The input is mechanical or electrical and the output is mechanical or electrical

*Learning Objective: Analyze the functional operation of synchros and resolvers and recognize associated troubleshooting aids.*

3-8. Basic synchro torque indicating systems are comprised of a/an

1. rotor and stator
2. armature and field
3. transmitter and receiver
4. differential synchro and control transformer

3-9. The operation of a synchro is similar to the operation of a/an

1. electrical motor
2. transformer
3. capacitor
4. resistor

3-10. A synchro is generally made up of a

1. one-winding rotor and one-winding strator
2. three-winding rotor and one-winding stator
3. one-winding rotor and three-winding stator
4. three-winding rotor and three-winding stator

3-11. The excitation voltage is applied to the primary winding of a synchro unit by means of

1. sliprings
2. insulated blocks
3. sheet steel laminations
4. insulated terminal boards

3-12. The output of a torque synchro system is
__________(A)__________ and would be
(mechanical, electrical)
utilized to position ____(B)____ loads.
(heavy, light)

1. (A) mechanical, (B) heavy
2. (A) mechanical, (B) light
3. (A) electrical, (B) heavy
4. (A) electrical, (B) light

3-13. The size of the windings of a synchro may be reduced if it is designed

1. for a lower excitation frequency
2. for a higher excitation frequency
3. with a higher number of turns in the rotor winding
4. with a higher number of turns in the stator windings

3-14. The stator windings of the synchro are electrically displaced from each other by an angle of

1. 60 degrees
2. 120 degrees
3. 180 degrees
4. 240 degrees

3-15. The voltages induced in the stator windings of a synchro vary because of the

1. applied excitation voltage
2. position of the rotor only
3. amount of voltage applied to the rotor
4. relative positions of the rotor and stator

3-16. What is the voltage induced in one stator winding of a 115-volt synchro if the rotor winding is parallel to it?

1. 52 volts
2. 78 volts
3. 90 volts
4. 115 volts

3-17. The proper operation of the synchro can be checked by comparing

1. rotor voltage readings with rotor position
2. stator voltage readings with stator position
3. stator voltage readings with rotor position
4. stator position with rotor voltage readings

3-18. Which procedure should be used to check the mechanical operation of a synchro receiver?

1. Energize the system and vary the input to the receiver
2. Deenergize the system and vary the input to the receiver
3. Deenergize the system and turn the rotor by hand
4. Energize the system and turn the rotor by hand

3-19. The stator windings of a resolver are physically displaced from each other by an angle of

1. 60 degrees
2. 90 degrees
3. 120 degrees
4. 150 degrees

3-20. In what manner does the most common form of resolver differ from a synchro?

1. The type of inputs
2. Unlimited rotor rotation
3. The variable transformer type of operation
4. The number of windings in the rotor and stator

3-21. The maintenance of a resolver that normally should be accomplished on board ship consists of

1. alignment tests and replacement of the resolver
2. alignment tests and replacement of the bearing within the resolver
3. adjustments to the compensating circuits and replacement of the compensating resistors
4. adjustments to the compensating circuits and replacement of the resolver

*Learning Objective: List the general characteristics and the principles of operation of inductosyns and microsyns.*

3-22. What total number of degrees of rotation of the inductosyn rotor are needed to complete a sine and cosine cycle?

1. 2 degrees
2. 8 degrees
3. 90 degrees
4. 180 degrees

3-23. What total number of windings of an inductosyn are used to produce a sine and cosine function?

1. One stator winding and one rotor winding
2. Two stator windings and two rotor windings
3. Two stator windings and one rotor winding
4. One stator winding and two rotor windings

3-24. What total number of sine and cosine functions will a 40-sector inductosyn produce in one revolution of the rotor?

1. One of each
2. Twenty of each
3. Forty of each
4. Eighty of each

3-25. What electrical component is used to reduce the varying amounts of resistance introduced by the inductosyn rotor sliprings?

1. Choke
2. Transformer
3. Rectifier
4. Capacitor

3-26. Voltage to the windings of an inductosyn should never exceed

1. 0.2 volt
2. 1.0 volt
3. 45.0 volts
4. 72.0 volts

3-27. The 1 degree mechanical position of a rotor in an inductosyn corresponds to the electrical position of the cosine output of

1. 270 degrees
2. 180 degrees
3. 90 degrees
4. 45 degrees

3-28. What total number of windings, if any, are coiled on each rotor pole of an 8-pole microsyn?

1. One
2. Two
3. Zero
4. Four

3-29. What is the purpose of the rotor in an 8-pole microsyn?

1. To act as a secondary winding for the stator windings
2. To act as the cosine winding during one part of a vector and the sine winding during the other part of the vector
3. To change an electrical signal to a mechanical order
4. To change the reluctance of the magnetic paths between the stator poles

3-30. What characteristics of the output voltage of a microsyn transmitter indicate (A) the amount of rotor movement and (B) the direction of rotor movement?

1. (A) amplitude, (B) frequency
2. (A) amplitude, (B) phase
3. (A) frequency, (B) phase
4. (A) frequency, (B) amplitude

3-31. Assume that the microsyn is used as a receiver. What will be the effect of applying only the reference voltage to the device?

1. The rotor will position itself to its zero position
2. The rotor will turn at a low speed
3. The rotor will turn at a high speed
4. The rotor will oscillate in an attempt to align itself with the two sets of poles

3-32. What are the inputs of a microsyn when used as (A) a receiver, and (B) a transmitter?

1. (A) electrical, (B) mechanical
2. (A) mechanical, (B) electrical
3. (A) mechanical, (B) mechanical
4. (A) electrical, (B) electrical

3-33. The output of a microsyn receiver is in the form of a variable

1. resistance
2. voltage
3. current
4. torque

*Learning Objective: Define the basic operation of bridge circuits, precision linear variable resistors, and tachometer generators.*

3-34. The balanced bridge circuit has two potentiometers of the same value connected in ____(A)____ (series, parallel) and connected to a ____(B)____ (different, common) supply.

1. (A) series, (B) different
2. (A) series, (B) common
3. (A) parallel, (B) different
4. (A) parallel, (B) common

For item 3-35, refer to figure 4-19 of the textbook, and assume the bearing of the missile is changed to the left.

3-35. The arm of the potentiometer on the left will move ____(A)____ (up, down) and the arm of the potentiometer on the right will move ____(B)____ (up, down).

1. (A) down, (B) down
2. (A) down, (B) up
3. (A) up, (B) up
4. (A) up, (B) down

Items 3-36 through 3-38 cover the precision linear variable resistor as shown in figure 4-20 of the textbook. Judge each item as either True or False.

3-36. The quantity that is to be changed to an analog voltage is an electrical input to this circuit.

3-37. The potentiometer is used to interpolate between various voltage levels.

3-38. The potentiometer is linear and, therefore, the output is directly proportional to the input signal.

3-39. What range value is represented by the output of a tachometer generator driven by a range drive shaft?

1. Difference between present and future range
2. Present range
3. Future range
4. Range rate

---

In items 3-40 through 3-42, select from column B the characteristic of the output voltage from an a.c. tach that is controlled by the input to the a.c. tach in column A.

| | A. INPUTS | B. CHARACTERISTICS |
|---|---|---|
| 3-40. | The rotation rate of the rotor | 1. Amplitude |
| | | 2. Frequency |
| 3-41. | The rotation direction of the rotor | 3. Phase |
| | | 4. Polarity |
| 3-42. | The cycle rate of the supply voltage | |

---

3-43. What characteristic of the output voltage from a d.c. tach is controlled by the direction of rotation of its rotor?

1. Phase
2. Polarity
3. Frequency
4. Amplitude

*Learning Objective: Analyze the functional operation of a basic servomechanism.*

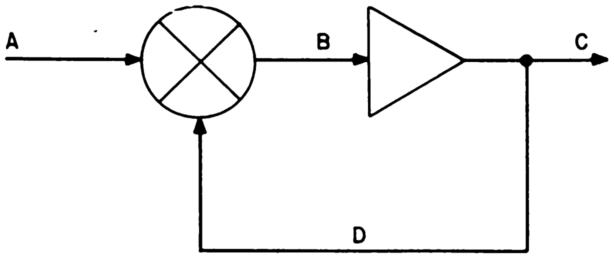

Figure 3-A.--Elementary servomechanism.

3-44. Which letter in figure 3-A represents the signal that indicates the desired action of the servo?

1. A
2. B
3. C
4. D

3-45. Which of the following expressions describes a portion of the elementary action of the servo shown in figure 3-A?

1. A ≠ D therefore there is a signal at B
2. A = D therefore there is a signal at B
3. A = B = C therefore there is a signal at D
4. A ≠ B therefore there is no signal at D

3-46. Which letter in figure 3-A represents the transmit portion of the servo?

1. A
2. B
3. C
4. D

3-47. In figure 3-A, if A represents a 10 degree CW rotation, then C should move

1. 10 degrees CW
2. 10 degrees CCW
3. 20 degrees CW
4. 20 degrees CCW

3-48. The purpose of the error reducer section of a servo is to

1. generate an error signal
2. increase the weak error signal
3. reduce the error signal to zero
4. compare the input signal with the feedback signal

3-49. What type of device is the error detector section of the servo?

1. Electromechanical
2. Electromagnetic
3. Mechanical
4. Electronic

3-50. The input to the amplifier section of the servo will be zero when the

1. error reducer output is maximum
2. input and feedback signals are equal
3. input and feedback signals are not equal
4. input and output shafts are at different positions

3-51. In figure 5-2 of the textbook, which signal indicates the position and motion of the output shaft?

1. Input signal
2. Error signal
3. Feedback signal
4. Amplified error signal

3-52. A servo is in correspondence when the

1. error detector has an output
2. error reducer has an output
3. input and output shafts are at the same position
4. input and output shafts are at different positions

3-53. When a servo system utilizes a multispeed transmission system, the accuracy of the servo is

1. reduced
2. increased
3. slightly decreased
4. the same as without this system

3-54. What is the voltage signal called that is used in multispeed transmission systems to stop the servo from synchronization at a false null point?

1. Position
2. Stickoff
3. Coarse
4. Null

3-55. The act of changing a d.c. voltage to an a.c. voltage signal is called
____(A)____ and the act of
(modulation, demodulation)
changing an a.c. voltage signal to a d.c. voltage is called ____(B)____ .
(modulation, demodulation)

1. (A) modulation, (B) demodulation
2. (A) modulation, (B) modulation
3. (A) demodulation, (B) modulation
4. (A) demodulation, (B) demodulation

3-56. What basic processes are used to produce (A) digital quantities and (B) analog quantities?

1. (A) counting, (B) counting
2. (A) counting, (B) measuring
3. (A) measuring, (B) counting
4. (A) measuring, (B) measuring

3-57. Which of the following is NOT an inherent advantage of a servoamplifier?

1. Low noise level
2. Impedance matching ability
3. Flat amplitude response over a band of frequencies
4. Large variable phase shift with respect to a reference voltage

3-58. The purpose of a preamplifier, when used with a servoamplifier, is to

1. increase the servo error signal
2. amplify the servo output signal
3. act as an amplifier for the response voltage
4. decrease the response time of the servoloop

3-59. What is the result of increasing the gain of a servo system?

1. Error is increased
2. Response is decreased
3. Stability is decreased
4. Stability is increased

3-60. The condition of the servo system called "hunting" is caused by

1. high gain
2. lost motion
3. random noise
4. load inertia

3-61. What method can be used to dampen and smooth out the operation of a servo system?

1. Introduce a feedback voltage to aid the signal voltage
2. Allow the servo output to move more freely
3. Restrain the output physically
4. Increase the system gain

*Learning Objective: Explain the basic operation of the functional sections of a longitude servo utilized in fire control equipment.*

3-62. A control transformer (CT) geared to operate at a 1 speed is considered as a
____(A)____ input to a servo and one
(coarse, fine)
that is geared at a 180 speed is considered as a ____(B)____ input.
(coarse, fine)

1. (A) coarse, (B) fine
2. (A) coarse, (B) coarse
3. (A) fine, (B) coarse
4. (A) fine, (B) fine

For items 3-63 through 3-65, refer to figure 5-4 of the textbook.

3-63. Diode net #1 clips the ____(A)____
(coarse, fine)
signal to a level of ____(B)____ .
(1.5 volts, 3.3 volts)

1. (A) coarse, (B) 1.5 volts
2. (A) coarse, (B) 3.3 volts
3. (A) fine, (B) 1.5 volts
4. (A) fine, (B) 3.3 volts

3-64. The intermediate signal input voltage (P-12) is in parallel with the

1. common terminal (P-3)
2. fine signal voltage (P-15) only
3. coarse signal voltage (P-11) only
4. coarse and fine signal voltages (P-11 and P-15)

3-65. What is the sequence of CT controlling signals applied to the servoamplifier when nulling a servo that is far out of alignment?

1. Fine, fine-intermediate, coarse
2. Coarse, intermediate-fine, fine
3. Intermediate, fine-intermediate, coarse
4. Coarse-intermediate, intermediate-fine, fine

3-66. The output signal of the servoamplifier, figure 5-5 of the textbook, that is fed to the control winding of the servomotor, has what relationship to the input error signal?

1. Proportional and in phase
2. Proportional and 180 degrees out of phase
3. Inversely proportional and in phase
4. Inversely proportional and 180 degrees out of phase

3-67. In a split-phase bi-directional servomotor, what controls the (A) speed of rotation and (B) the direction of rotation?

1. (A) phase difference between the voltages on the control winding and the reference winding, (B) amplitude of the voltage on the control winding
2. (A) phase difference between voltages on the control and the reference winding, (B) amplitude of the voltage on the reference winding
3. (A) amplitude of the voltage on the reference winding, (B) phase difference between voltages on the control winding and the reference winding
4. (A) amplitude of the voltage on the control winding, (B) phase difference between voltages on the control winding and the reference winding

3-68. The null detector will produce an indication once the servo error exceeds

1. 5 minutes of arc
2. 10 minutes of arc
3. 15 minutes of arc
4. 20 minutes of arc

For items 3-69 and 3-70, refer to figure 5-6 of the textbook.

3-69. With the relay contacts as shown, which of the following conditions would exist in the circuit?

1. Error signal present, Q4 is cutoff, and Q5 is conducting
2. Error signal is present, Q4 is conducting, and Q5 is cutoff
3. No error is present, Q4 is cutoff, and Q5 is conducting
4. No error signal present, Q4 is conducting, and Q5 is cutoff

3-70. With the green NULL light lit, which of the following conditions could exist in the circuit?

1. No error signal present, Q4 conducting, and Q5 is cutoff
2. No error signal present, Q4 conducting, and Q5 conducting
3. Small error signal present, Q4 cutoff, and Q5 conducting
4. Small error signal present, Q4 cutoff, and Q5 cutoff

# Assignment 4

Servomechanisms (continued); Digital Computers

**Textbook Assignment:** Fire Control Technician (B) 3&2, Vol. 1, NAVEDTRA 10211-B1; pages 62-80

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*Learning Objective: Describe the gating sequence performed by the switch driver and motor circuit when driving a switch to an ordered position.*

Items 4-1 through 4-9 are to be judged True or False based on the text discussion of the switch driver and motor circuit.

4-1. The maximum number of snap-slide switches this circuit can control is eight.

4-2. There are only two positions on any one snap-slide switch.

4-3. The snap-slide switches are driven by a d.c. motor.

4-4. The position of the snap-slide switches is determined by the driver circuit.

4-5. The d.c. motor always rotates counterclockwise.

4-6. A 28-volt position signal on P8 of figure 5-7 of the textbook will gate SCR 2 and 3.

4-7. A 28-volt position signal on P5 of figure 5-7 of the textbook will cause current flow through F2 and through the snap-slide switch contacts D3 and D4.

4-8. Once a position signal sets the snap-slide switches, they will not move until another position signal is received.

4-9. Capacitors C1 and C2 shift the phase of the d.c. motor current to reduce the torque.

*Learning Objective: Analyze the modification functions performed by analog computing servos.*

In items 4-10 through 4-13, select from column B the basic analog operation that is described in column A.

| | A. DESCRIPTION | | B. OPERATION |
|---|---|---|---|
| 4-10. | Filtering of extraneous signals | 1. | Modification |
| | | 2. | Monitoring |
| 4-11. | Checking the electrical level of an analog signal | 3. | Generation |
| 4-12. | Making a signal phase sensitive | | |
| 4-13. | Conversion of a physical quantity into a proportional analog voltage | | |

---

4-14. In figure 5-8 of the textbook, the output at P8 is amplified and _____(A)_____ (in phase, out of phase) with respect to the input signal, and the output at P1 is amplified and _____(B)_____ (in phase, out of phase) with respect to the input signal.

1. (A) in phase, (B) out of phase
2. (A) in phase, (B) in phase
3. (A) out of phase, (B) in phase
4. (A) out of phase, (B) out of phase

4-15. What is considered to be the real job of a summing circuit?

1. To determine the algebraic sum of analog voltages
2. To change the algebraic summation of voltages to a scalar quantity
3. To change fixed voltages to a scalar quantity
4. To attenuate analog voltage signals

4-16. If the input to E1 of figure 5-9 of the textbook is scaled as shown but the input to E2 is scaled one volt/40 feet, what would the proper value of R2 be for proper summation?

1. 1 megaohm
2. 2 megaohms
3. 3 megaohms
4. 4 megaohms

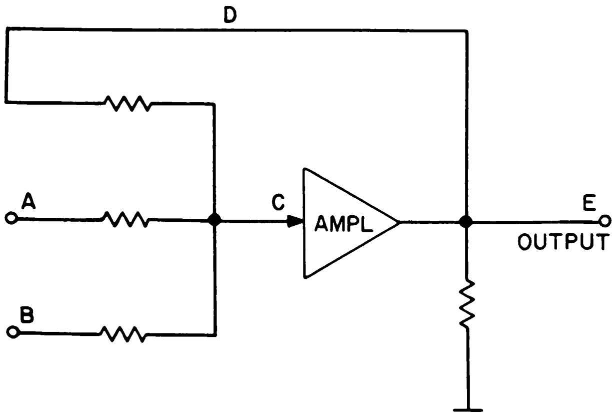

Figure 4-A.--Summing amplifier.

For items 4-17 and 4-18, use figure 4-A and the below alternatives.

A. A + B + C = D
B. A + B + D = C
C. A - B = C
D. A + B = D

4-17. Which expression represents the operation of the circuit?

1. A
2. B
3. C
4. D

4-18. Which expression represents a null condition in this circuit?

1. A
2. B
3. C
4. D

4-19. Which of the following functions does the feedback loop accomplish in a summation network?

1. Modifies the output signal without affecting the input signal
2. Compensates for fluctuations in the power supply
3. Isolates the output from the input
4. All of the above functions

---

In items 4-20 through 4-22, refer to figure 5-12 of the textbook and select from column B the circuit case that exists with each of the conditions described in column A.

| A. CONDITIONS | B. CASE |
|---|---|
| 4-20. Large current through CR3 and R1 with a small current through CR4 and R2. Input polarity is positive. | 1. 5<br>2. 4<br>3. 3 |
| 4-21. Large current through CR4 and R2 with a small current through CR3 and R1. Input polarity is negative. | 4. 2 |
| 4-22. Large current through CR1 and R1 with a small current through CR2 and R2. Input polarity is positive. | |

---

For items 4-23 and 4-24, refer to figure 5-13 of the textbook.

4-23. When the signal and reference voltages are in phase and both are on the positive half-cycle, the larger current flows through

1. CR1 and R2
2. CR2 and R1
3. CR3 and R1
4. CR4 and R2

4-24. When the signal and reference voltages are 180 degrees out of phase and the signal voltage is positive and the reference voltage is negative, the larger current flows through

1. CR1 and R2
2. CR2 and R1
3. CR3 and R1
4. CR4 and R2

*Learning Objective: Specify the basic function of each of the four sections of a digital computer.*

4-25. Which of the following functions is/are performed by the digital computer used in a weapon system?

1. Accepting and utilizing data
2. Performing computations
3. Producing usable data for the weapon
4. All of the above functions

In items 4-26 through 4-30, select the computer unit in column B that performs the function listed in column A.

| | A. FUNCTIONS | B. UNITS |
|---|---|---|
| 4-26. | Preserves information for later use | 1. Arithmetic |
| 4-27. | Compares quantities to arrive at a logical decision | 2. Control |
| 4-28. | Transfers data between the computer and the system | 3. Memory |
| 4-29. | Causes all parts of the computer to act as an integral system | 4. Input/ output |
| 4-30. | Produces answers to given questions in the form of a "yes" or "no" | |

*Learning Objective: Associate logic functions and logic modules with their application in digital computers.*

4-31. In digital computer language, a decimal two would appear in its encoded binary form as

1. no pulse, pulse, pulse
2. no pulse, pulse, no pulse
3. pulse, pulse, no pulse
4. pulse, no pulse, no pulse

Item 4-32 is to be judged True or False.

4-32. In a digital computer using negative logic, the less negative of two input signals would tend to inhibit a gating circuit.

4-33. What total number of values may a variable assume in a digital computer using the binary system?

1. 1
2. 2
3. 4
4. 8

4-34. The "and" operation is expressed as which of the following?

1. AB
2. A • B
3. A x B
4. All of the above

4-35. Which expression describes an "or" operation?

1. A + B
2. A - B
3. A x B
4. A ÷ B

4-36. The "not" operation is symbolized by which of the following?

1. $\ddot{A}$
2. $\dot{A}$
3. $\bar{A}$
4. All of the above

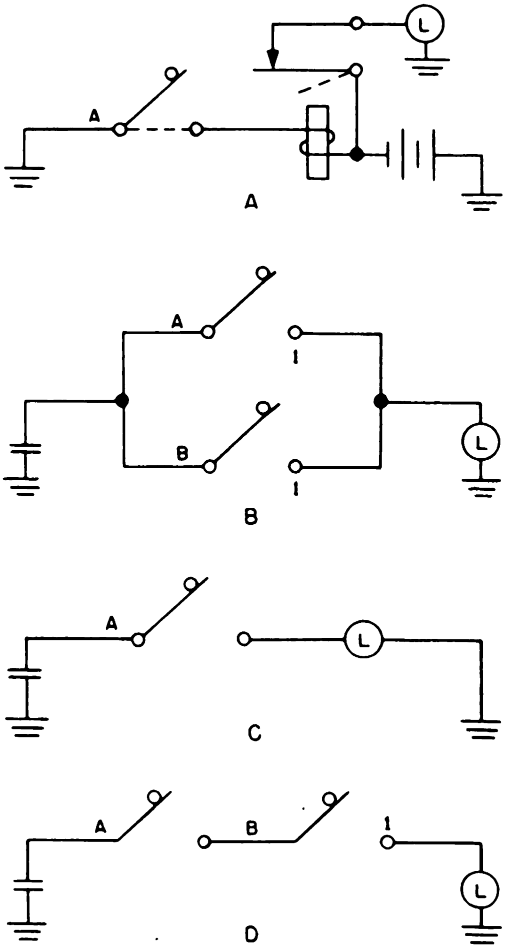

Figure 4-B.--Logic circuits.

In items 4-37 through 4-39, select from column B the circuit in figure 4-B that performs the logic operation in column A.

| | A. OPERATION | B. CIRCUIT |
|---|---|---|
| 4-37. | "Not" | 1. A |
| 4-38. | "And" | 2. B |
| 4-39. | "Or" | 3. C |
| | | 4. D |

4-40. Consider an AND function with inputs, A and B. The function is true

1. if either A or B, or both, are false
2. if either A or B, or both, are true
3. if either A or B is true, but not both
4. only if A and B are both true

4-41. The function, f = A + B, has a value of 0 when

1. A = 0 and B = 0
2. A = 0 and B = 1
3. A = 1 and B = 0
4. A = 1 and B = 1

4-42. Light A can be turned on from the bottom of the ladder and can also be turned on from the top of the ladder. What logic circuit can be used to represent this statement?

1. AND
2. OR
3. NOR
4. NAND

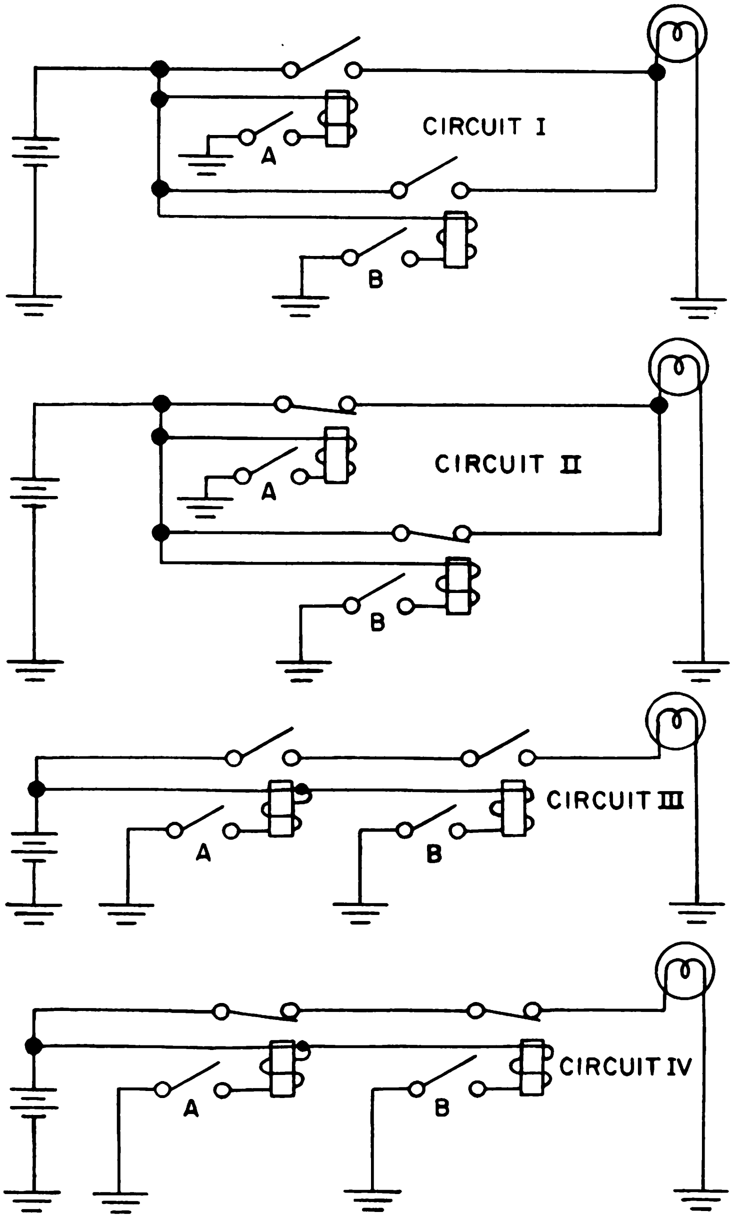

Figure 4-C.--Switching circuits (lamp lit, f = 1; lamp unlit, f = 0).

To answer items 4-43 through 4-46, refer to figure 4-C. Inputs to the circuits are represented by the switches marked A and B. An open input switch represents a 0 input and a closed input switch represents a 1 input.

4-43. Which circuit represents a NOR circuit?

1. I
2. II
3. III
4. IV

4-44. In the NOR circuit, the lamp lights only if

1. both A and B are open
2. both A and B are closed
3. either A or B is open
4. either A or B is closed

4-45. Which circuit represents a NAND circuit?

1. I
2. II
3. III
4. IV

4-46. In the NAND circuit, the lamp remains unlighted only if

1. both A and B are open
2. both A and B are closed
3. either A or B is open
4. either A or B is closed

Item 4-47 is to be judged True or False.

4-47. An "exclusive or" circuit will produce a logic "1" output if input signals A and B are both logic "1's."

4-48. Which inputs are required in the NOR circuit in figure 6-7 of your textbook to obtain a logic "1" output?

1. One input at a logic "0" level
2. All inputs at a logic "0" level
3. One input at a logic "1" level
4. All inputs at a logic "1" level

4-49. Refer to figure 6-8A of your textbook. What combination of inputs produces a logic "1" at the output?

1. A positive, B positive
2. A positive, B negative
3. A negative, B position
4. A negative, B negative

4-50. Refer to figure 6-8B of your textbook and assume the inputs are A, positive, and B, negative. What are the states of conduction of transistors Q1 and Q2?

1. Q1 conducting, Q2 conducting
2. Q1 conducting, Q2 cutoff
3. Q1 cutoff, Q2 conducting
4. Q1 cutoff, Q2 cutoff

4-51. A flip-flop is a form of multivibrator with characteristics such that it will remain in either of two states until an input to the other state occurs. A device having this characteristic is said to be

1. astable
2. bistable
3. monostable
4. quasistable

4-52. If a flip-flop contains a logic "0," what are the set and reset outputs, respectively?

1. 0, 0
2 0, 1
3. 1, 0
4. 1, 1

To answer items 4-53 and 4-54, refer to figure 6-10 of your textbook.

4-53. A set pulse sets the counter to a binary

1. 000
2. 001
3. 011
4. 111

4-54. The first advance pulse after the set pulse sets the counter to a binary

1. 001
2. 010
3. 011
4. 100

4-55. The function of the transfer pulse in the operation of the double-ranked counter is to transfer the

1. count in rank one into rank two
2. count in FF 0-1 to FF 2-3, FF 2-3 to FF 4-5, etc.
3. advance pulse from rank one to rank two
4. counter output from the set side to the reset side of the flip-flops

4-56. Assume that both ranks of the counter shown in figure 6-11 of your textbook contain the count, 001. When the next advance pulse arrives, which AND gates in rank one are satisfied?

1. Set side of FF 4-5 and set side of FF 8-9
2. Set side of FF 0-1 and set side of FF 4-5
3. Set side of FF 0-1 and reset side of FF 4-5
4. Reset side of FF 0-1 and set side of FF 4-5

4-57. A NOR circuit is equivalent to

1. two OR gates in parallel
2. an OR gate with inverted inputs
3. an OR gate followed by an inverter
4. an OR gate followed by an AND gate

4-58. In order for a 1 to be stored in the flip-flop module by means of the set input, a logic "1" must be present at the set input and a clock pulse must simultaneously appear at the

1. reset input
2. reset clear input
3. set trigger input
4. reset trigger input

4-59. A logic 1 can be stored in the flip-flop asynchronously (in the absence of a clock pulse) by applying a logic 1 to the

1. reset input
2. reset clear input
3. set clear input
4. set trigger input

4-60. A right shift has the effect of performing what binary arithmetic operation on the contents of a register?

1. Adding 0
2. Subtracting 10
3. Dividing by 10
4. Multiplying by 10

4-61. At a given stage in a register, the AND gate associated with the right shift circuit has two inputs. One is from the right-shift control and the other is from the

1. reset output of the next higher stage
2. reset output of the next lower stage
3. set output of the next higher stage
4. set output of the next lower stage

4-62. What arithmetic operation is performed on a word in a register by shifting it to the left?

1. Adding 10
2. Subtracting 2
3. Multiplying by 10
4. Multiplying by 2

# Assignment 5

Digital Computers (continued)

**Textbook Assignment:** Fire Control Technician (B) 3&2, Vol. 1, NAVEDTRA 10211-B1; pages 80-98

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*Learning Objective: Follow the basic routines and steps required to perform the four arithmetic operations in a digital computer.*

5-1. What three registers and associated logic circuitry make up the arithmetic section of the computer?

1. U, S, and Z
2. U, R, and X
3. A, R, and S
4. A, Q, and X

---

To answer items 5-2 through 5-6, select from column B the register that performs the function listed in column A.

| | A. FUNCTIONS | B. REGISTERS |
|---|---|---|
| 5-2. | Operates in conjunction with one other single register only | 1. A<br>2. Q |
| 5-3. | Provides communication between sections of the computer | 3. U<br>4. X |
| 5-4. | Serves as the auxiliary arithmetic register | |
| 5-5. | Serves as the program control register | |
| 5-6. | Usually accumulates and retains the results of an arithmetic operation | |

---

5-7. Which of the following operations is accomplished by repeated adding and shifting?

1. Division
2. Comparison
3. Subtraction
4. Multiplication

5-8. What is the result of adding a binary "0" to a binary "1"?

1. 1
2. 0
3. 1 with a carry of 1
4. 0 with a carry of 1

5-9. Which of the following binary subtraction operations produces a difference of 1 and a borrow of 1?

1. 0 - 0
2. 0 - 1
3. 1 - 0
4. 1 - 1

5-10. The one's complement of a binary number may be obtained by subtracting each bit from

1. 1 and adding 1 to the most significant bit
2. 1 and adding 1 to the least significant bit
3. 1
4. Binary 10

5-11. An equivalent, and practical, method for obtaining the one's complement of a binary number is to

1. end-around left shift the number
2. end-around right shift the number
3. end-off right shift the number
4. invert each bit in the number

5-12. What is the one's complement of 011010?

1. 110101
2. 100111
3. 100101
4. 100100

5-13. The subtraction problem, 11010 - 01101, can be performed as an addition. Using the one's complement, the first step is to find the one's complement of 01101. What computation represents the second step?

1. 11010 + 10010
2. 11010 + 10011
3. 100000 + 11010
4. 100101 + 01101

5-14. Which of the following computations represents a step in the process of adding 0100011 to 011101, using the one's complement and the subtractive process?

1. 100010 + 1011100
2. 100010 - 1011100
3. 011101 - 1011100
4. 011101 - 0100011

5-15. For the purpose of carrying out the subtractive process, the minuend and subtrahend are represented, respectively, by

1. A and $\bar{X}$
2. A and X
3. $\bar{X}$ and A
4. X and A

5-16. In the process of subtracting the complement of the contents of the X register from the contents of the A register, assume that at stage n-1 a borrow is generated, that is $A_{n-1} - \bar{X}_{n-1}$ generates a borrow. The borrow must be made from

1. $A_n$
2. $\bar{X}_n$
3. $A_{n+1}$
4. $A_{n-2}$

5-17. The first condition for toggling $A_n$ is satisfied when

1. $A_n = 0$
2. $\bar{X}_n = 1$
3. $X_n = 1$
4. $\bar{X}_{n-1} = 0$

5-18. The second condition for toggling $A_n$ is satisfied when

1. $A_{n-1} = 1$ and $\bar{X}_n = 0$
2. $A_{n-1} = 1$ and $A_n = 0$
3. $A_{n-1} = 1$ and $\bar{X}_{n-1} = 1$
4. $A_{n-1} = 0$ and $\bar{X}_{n-1} = 1$

5-19. $A_n$ is actually toggled when

1. neither of the conditions is satisfied
2. only one of the conditions is satisfied
3. both of the conditions are satisfied
4. either of the conditions, or both, are satisfied

To answer items 5-20 through 5-22, assume that the contents of the A and X registers are:

$A = 0_5\ 1_4\ 1_3\ 0_2\ 1_1\ 1_0$

$X = 0_5\ 1_4\ 1_3\ 1_2\ 0_1\ 1_0$

5-20. What is the logical difference when $\bar{X}$ is subtracted from A?

1. 000110
2. 010110
3. 111000
4. 111001

5-21. From what stage(s) of A is a borrow to be made?

1. 0 only
2. 0 and 3
3. 1 and 2
4. 2, 3, and 5

5-22. What stages of A are to be toggled?

1. 2 and 4
2. 1, 4, and 5
3. 0, 1, and 5
4. 0, 2, and 3

5-23. What is the function of the borrow pyramid shown in figure 6-12 of your textbook?

1. Accumulates results of the partial add operation
2. Complements the contents of $X^1$ and transfers it to $X^2$
3. Accepts overflow digits resulting from an add operation
4. Determines whether one of the two toggling conditions exists

5-24. During the multiplication sequence, what registers contain the multiplier and multiplicand, respectively?

1. A and Q
2. Q and A
3. Q and X
4. X and Q

5-25. When a bit in the multiplier is examined and found to be a 1, what subsequent action results?

1. The multiplicand is added to the multiplier and the multiplicand is shifted to the right
2. The multiplicand is added to the multiplier and the multiplier is shifted to the right
3. The multiplicand is added to the partial product and the partial product is shifted to the right
4. The multiplier is added to the partial product and the partial product is shifted to the left

5-26. What is the only binary multiplication between single bits that results in a product of 1?

1. 1 x 1
2. 1 x 0
3. 0 x 1
4. 0 x 0

5-27. What is the location of the current multiplier bit during the multiplication sequence?

1. Most significant digit of the A register
2. Most significant digit of the Q register
3. Least significant digit of the A register
4. Least significant digit of the Q register

To answer items 5-28 through 5-30, use multiplication steps similar to those shown on page 85 of your textbook and consider the following problem: multiplier = 00101
multiplicand = 01101

5-28. What are the contents of the A and Q registers at step 1?

1. A - 00101, Q - 01101
2. A - 00000, Q - 01101
3. A - 00000, Q - 00101
4. A - 00000, Q - 00000

5-29. What are the contents of A and Q at step 2?

1. A - 00110, Q - 10010
2. A - 00101, Q - 00110
3. A - 00000, Q - 00110
4. A - 00000, Q - 00010

5-30. What is the final product?

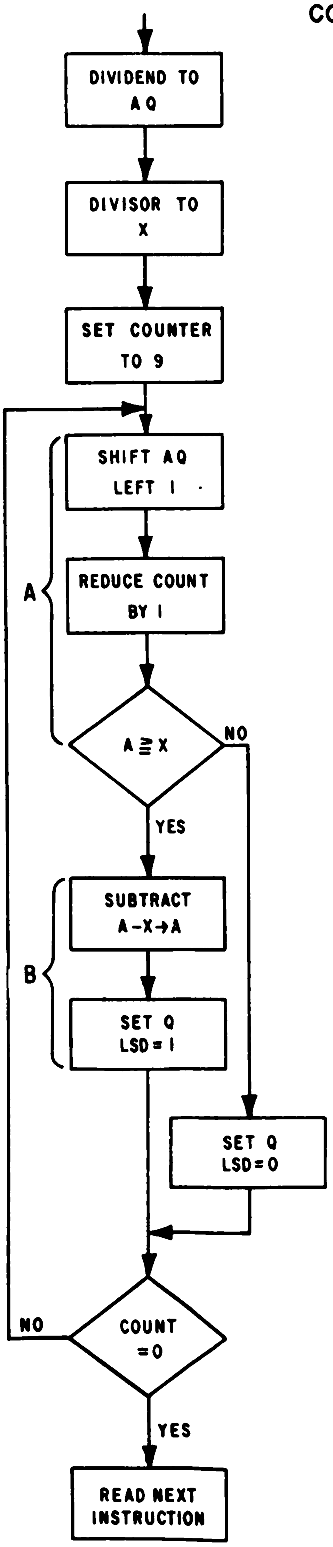
1. 1010011
2. 1001101
3. 1001000
4. 1000001

5-31. At the end of the multiplication process, the product is located in the

1. A register only
2. Q register only
3. A and Q registers
4. A and X registers

5-32. The control quantity, used to determine the number of steps needed to complete a division or multiplication problem, is set in the

1. A register
2. P register
3. R register
4. X register



X-REGISTER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 |

| COUNTER | | A-REGISTER | | | | | | | | | Q-REGISTER | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 |
| | | | | | | | | | | | | | | | | | | | |
| 8 | A | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 |
| | B | | | | | | | | | | | | | | | | | | |
| 7 | A | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| | B | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 |
| 6 | A | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |
| | B | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 |
| 5 | A | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 |
| | B | | | | | | | | | | | | | | | | | | |
| 4 | A | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 |
| | B | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 |
| 3 | A | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 |
| | B | | | | | | | | | | | | | | | | | | |
| 2 | A | | | | | | | | | | | | | | | | | | |
| | B | | | | | | | | | | | | | | | | | | |
| 1 | A | | | | | | | | | | | | | | | | | | |
| | B | | | | | | | | | | | | | | | | | | |
| 0 | A | | | | | | | | | | | | | | | | | | |
| | B | | | | | | | | | | | | | | | | | | |

Figure 5-A.--Division by subtraction and left shifting.

To answer items 5-33 through 5-36, use the flow chart and diagram in figure 5-A to perform the division operation, 110000000101 ÷ 11100101, by the repetitive subtraction and left shifting method. Note that at each count the process is subdivided into two parts, a and b, which correspond to the indicated steps in the flow chart. The diagram is filled out to count 3 remaining; the student should complete the diagram for the remaining counts.

5-33. When 7 counts are remaining, what action constitutes step b?

1. Shift AQ left
2. Shift AQ left and set Q LSD to 1
3. Subtract X from A
4. Subtract X from A and set Q LSD to 1

5-34. At what points in the process, in terms of counts remaining, is "no the answer to the question, "A≥X"?

1. 8, 5, 4, 2
2. 8, 5, 3
3. 8, 5, 2, 1
4. 8, 7, 4, 2

5-35. What is the content of the AQ register at part b of the process when 2 counts are remaining?

1. 001100100001101101
2. 010101011110110101
3. 011001000011011010
4. 110010000110110100

5-36. What is the quotient?

1. 10110001
2. 10111011
3. 11001011
4. 11010111

5-37. In which of the following cases will a divide fault result?

1. The quotient is too large for the Q register
2. The dividend is negative and the divisor is positive
3. At some step X is greater than A
4. At some step A is greater than X

*Learning Objective: Identify the terms associated with, and the methods of magnetizing, the memory unit.*

In items 5-38 through 5-42, select the memory storage term in column B that is described by the characteristic listed in column A.

| | A. CHARACTERISTICS | B. STORAGE TERMS |
|---|---|---|
| 5-38. | Fast access time | 1. Static<br>2. Secondary |
| 5-39. | Contains information that is sent to the arithmetic section in blocks | 3. Internal<br>4. External |
| 5-40. | Contains stored information not directly accessible to the computer | |
| 5-41. | Low storage capacity | |
| 5-42. | Unlimited storage capacity | |

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5-43. What type of storage provides the same storage location for two different data words at two different times?

1. Random
2. Static
3. Dynamic
4. Erasable

5-44. Which of the following best describes series access?

1. Operating on all bits of a word during the same cycle
2. Operating on one bit of information at a time
3. Writing a word of information
4. Reading a word of information

Item 5-45 is to be judged True or False.

5-45. When comparing parallel and series access computer operation, the parallel operation has the advantage of lower cost.

5-46. In figure 6-13B of your textbook, the nonreturn to zero waveform is recorded as a

1. two-level signal that produces a single output for a single pulse or for an uninterrupted series of pulses
2. two-level signal that produces an output only with a series of uninterrupted pulses
3. three-level signal that produces an output only when a zero appears in the series of pulses
4. three-level signal that produces an output only with a series of uninterrupted pulses

*Learning Objective: Recognize the basic functional operation, advantages, and disadvantages of the various types of storage mediums.*

**5-47. For which of the following reasons is the magnetic drum a good storage device for a computer?**

1. **Relatively low cost**
2. **Information on the drum can be changed**
3. **Power loss does not effect the information on the drum**
4. **For all of the above reasons**

**5-48. The heads of a magnetic drum are staggered instead of being perfectly aligned in order to provide**

1. for mounting the read and write heads adjacent to each other
2. a greater number of channels
3. for a higher drum speed
4. shorter access time

**5-49. What is the average access time of a magnetic drum?**

1. One revolution
2. 2 milliseconds
3. 10 milliseconds
4. one-half revolution

**5-50. In a magnetic drum containing its own timing pulses, what is the reason calculation errors are not induced when drum speed varies?**

1. The computer calculating functions are synchronized with the timing pulses regardless of drum speed
2. The timing pulse generator does not vary the spacing between its output pulses
3. Access time remains constant regardless of drum speed
4. Drum speed varies access time

**5-51. Which of the following factors determines the binary level written into a ferrite core?**

1. **Polarity of the voltage applied**
2. **Magnitude of the magnetizing force**
3. **Direction of the magnetizing force**
4. **All of the above factors**

5-52. The storage capacity of a computer memory containing four matrices of 175 cores each is

1. 700 bits
2. 500 bits
3. 350 bits
4. 175 bits

To answer items 5-53 through 5-55, refer to figure 6-15 of your textbook.

5-53. Why is there no effect on the magnetic polarity of the cores in column one, when a pulse is applied to wire #1?

1. Wire #1 is a read-in wire
2. Wire #1 is a read-out wire
3. Two pulses must be applied to wire #1 to exceed the threshold value of the cores
4. The threshold value of a core is not exceeded by a pulse from a single wire

5-54. Passing pulses through wires 4 and C will cause the magnetic polarity to be switched in core

1. 9
2. 12
3. 4
4. 15

5-55. When a core changes its magnetization state, the readout pulse is taken from the

1. wire that caused the core to switch polarity
2. horizontal wire
3. vertical wire
4. sense wire

5-56. The waveform shown in figure 6-16C of your textbook is applied to a core to

1. "form" the core
2. determine if the core is usable in a computer
3. establish a level of residual magnetism in the core
4. remove any residual magnetism that may be in the core

5-57. A group of characters on a magnetic disk comprise a

1. record
2. track of information
3. cylinder of information
4. bank of information

**In items 5-58 through 5-61, select the track information from column B that performs the function listed in column A.**

| A. FUNCTIONS | B. INFORMATION |
|---|---|
| **5-58. Indicates the end of a data track** | 1. Record address |
| | 2. Index point |
| **5-59. Contains the information track number** | 3. Home address #1 |
| **5-60. Defines specific information areas** | 4. Gaps |
| **5-61. Utilized for timing functions** | |

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**5-62. Which unit of the magnetic disk file system provides decoded instructions for the magnetic disk modules?**

1. Disk storage unit
2. File control unit
3. Data decoding unit
4. Disk file controller unit

**5-63. The magnetic tape used as a computer storage device must have a very high quality recording surface in order that**

1. access time may be very short
2. information bits will not be missed
3. recorded data may be retained for varying lengths of time
4. the thickness of the magnetic surface will be uniform

**5-64. What is the primary benefit of using magnetic tape as a storage medium?**

1. The tape is not affected by extreme environmental conditions
2. Provides an inexpensive large storage capacity
3. No special handling precautions are required
4. Provides the shortest access time

*Learning Objective: Recognize the purpose and functional operation of the input/output section of a digital computer.*

5-65. The input/output section of a digital computer functions as a

1. means by which the memory section can "talk" to all other sections of the computer
2. means of communication between the arithmetic section and memory section
3. method of exchanging data between the computer and external equipment
4. method of exchanging data between external equipment

5-66. What undesirable characteristic of input/output devices must be compensated for to make them compatible with digital computers?

1. Poor transmission capabilities
2. Inconsistent data exchange rates
3. Inability to match the faster operating speed of the computer
4. Inability to match the slower operating speed of the computer

5-67. With respect to digital computers, the multiplexing operation consists of

1. utilizing devices not under direct control of the computer
2. using one channel and input/output device to provide inputs to the computer
3. using several channels and input/output devices to provide inputs to the computer
4. programming input cycles at the same time as computer calculations

5-68. Which is a function of the buffer storage registers during computer operation?

1. Storing data from the output device at a low speed
2. Storing data from the input device at a low speed
3. Transferring data to the computer memory at a low speed
4. Transferring data to the output device at a high speed

Item 5-69 is to be judged True or False.

5-69. Once the buffer operation is initiated, it is carried out automatically and independent of the main program.

5-70. Which of the following pairs of buffer channels forms an input/output transmission link for use with external equipment?

1. 1 and 2
2. 1 and 3
3. 2 and 3
4. 2 and 4

5-71. Assume that the d.c. line receiver receives a d.c. pulse of a given amplitude representing a logic 1. The circuit converts the logic voltage level to the corresponding computer logic level and the pulse appearing at the output will be a

1. logic 0, reduced in amplitude
2. logic 1, reduced in amplitude
3. logic 0, increased in amplitude
4. logic 1, increased in amplitude

5-72. In the exchange of data between the computer and external equipment, the data resume signal indicates that

1. an output buffer channel has been activated
2. the buffering operation has been terminated
3. the computer has placed a word in the output register
4. the data has been received and more information may be transmitted

5-73. Which of the following steps in the transmission of a word into the computer occurs first?

1. Computer activates input buffer channel
2. Computer produces input data resume signal
3. Equipment produces input data ready signal
4. Computer establishes equipment from which it is to receive data

5-74. Which of the following steps in the transmission of a word out of the computer terminates the operation?

1. Computer places the word in its output register
2. Computer turns off its output data ready signal
3. Equipment accepts output data ready signal
4. Equipment generates output data resume signal

# Assignment 6

**Inertial Devices**

**Textbook Assignment:** Fire Control Technician (B) 3&2, Vol. 1, NAVEDTRA 10211-B1; pages 99-120

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*Learning Objective: Relate the types of motion and laws of motion to inertial guidance.*

6-1. Two types of sensors used to measure the angular and linear motions of a Fleet Ballistic Missile (FBM) in flight are

1. synchros and gyroscopes
2. synchros and accelerometers
3. resolvers and accelerometers
4. gyroscopes and accelerometers

6-2. The motions detected in the FBM are measured with respect to

1. the missile flight path
2. the target's position
3. own ship's position
4. the Earth's surface

6-3. What is the relative motion between a ship traveling due north at 20 knots and a ship traveling due south at 20 knots?

1. Zero knots
2. 20 knots north
3. 20 knots south
4. 40 knots

Item 6-4 is to be judged True or False.

6-4. Linear motion is in a straight line, and angular motion is a rotation about an axis.

6-5. In accordance with Newton's first law of motion, the forces acting on a stationary object are

1. equal and opposite forces
2. unbalanced forces acting in one direction
3. unbalanced forces acting through the object's center of gravity
4. nonexistent; there are no forces acting on the object

6-6. Assume a ship is traveling in a straight line at a constant speed. If the mass of the ship is decreased, its velocity will ______(A)______ (increase, decrease) and if the propelling force applied to the ship is increased, its velocity will ______(B)______ (increase, decrease).

1. (A) increase, (B) decrease
2. (A) decrease, (B) increase
3. (A) increase, (B) increase
4. (A) decrease, (B) decrease

6-7. In accordance with Newton's third law of motion, which of the following statements is true?

1. The reaction will cancel the action
2. The reaction always precedes the action
3. The reaction is in the same direction as the action
4. The reaction is in the direction opposite to the action

6-8. The mass possessed by a body is

1. a property of matter
2. a force acting on the body
3. indirectly proportional to the body's weight
4. determined by the distance of the body from the center of the Earth

6-9. The momentum of a body in motion is

1. equal to the mass of the body
2. equal to the velocity of the body
3. a vector quantity whose direction is opposite to the body's velocity vector
4. a vector quantity whose direction is coincident with the body's velocity vector

In items 6-10 through 6-12, select the quantity in column B that is a result of the mathematical computation listed in column A.

| | A. COMPUTATIONS | B. QUANTITIES |
|---|---|---|
| 6-10. | Force multiplied by radius | 1. Mass |
| | | 2. Torque |
| 6-11. | Weight divided by gravity | 3. Acceleration |
| 6-12. | The unbalanced force divided by the mass | 4. Angular speed |

6-13. The radius through which a torque is applied is sometimes referred to as the

1. line of action
2. axis of rotation
3. plane of rotation
4. lever arm distance

6-14. The torque exerted on a rotating body is

1. directly proportional to the resistance of the body
2. indirectly proportional to the resistance of the body
3. directly proportional to the force applied to the body
4. indirectly proportional to the force applied to the body

6-15. Which of the following determine(s) the resistance offered by a body to a change in angular velocity?

1. Mass of the body only
2. Distribution of the body's mass only
3. Radius through which the torque is applied only
4. All of the above factors

6-16. The moment of inertia of a rotating body determines the

1. rotational axis of the body
2. lever arm distance of the body
3. time required to change the angular velocity of the body
4. torque required to change the angular velocity of the body

6-17. The moment of inertia of a body is decreased by

1. any change in angular velocity
2. a decrease in the radius of gyration
3. a decrease in angular velocity, only
4. an increase in angular velocity, only

6-18. What determines the angular momentum of a rotating body?

1. The magnitude of the force applied to the body
2. The magnitude of the torque exerted on the body
3. The moment of inertia and the angular velocity of the body
4. The magnitude of the torque exerted and the mass of the body

6-19. Where must an unbalanced force be applied to a rotating body to cause a translation of its rotational axis?

1. In the direction of rotation
2. Through the body's center of gravity
3. Opposite to the direction of rotation
4. At the radius of gyration of the body

Items 6-20 and 6-21 are based on figure 7-2 of the textbook. Item 6-20 is to be judged True or False.

6-20. The centrifugal force and the centripetal force are equal and opposite and therefore cancel each other.

6-21. The centrifugal force is caused by the
____(A)____ while the centripetal force
(cord, ball)
is caused by the ____(B)____.
(cord, ball)

1. (A) ball, (B) cord
2. (A) cord, (B) ball
3. (A) ball, (B) ball
4. (A) cord, (B) cord

*Learning Objective: Recognize the effects of the Earth's natural forces upon a missile during flight.*

6-22. The measurements made by the missile guidance system are

1. affected by external forces only during the first stage of powered flight
2. not affected by external forces since inertial devices are used
3. not affected by Earth motions since missile motions are independent of Earth motions
4. affected by the Earth's mass and motions

6-23. If no compensations were made for the coriolis effect, why would a missile launched directly upward from the Equator fall to the west of the launch point?

1. Earth's motions are not imparted to the missile
2. The centrifugal force acting on the missile decreases as the missile ascends
3. The rate of movement of the missile and launch point are unequal because of Earth's rotation
4. The centripetal force acting on the missile decreases as the missile ascends

6-24. The coriolis effect causes a missile launched in the northern hemisphere to deviate to the

1. left when missile flight is in a northward direction
2. left when missile flight is in a southward direction
3. left when missile flight has an east-west component
4. right regardless of the direction of missile flight

6-25. How does the magnitude of the coriolis effect vary along a missile flight path?

1. The magnitude will vary with latitude
2. The magnitude will vary with longitude
3. The magnitude is constant throughout the flight path
4. The magnitude will vary with the vertical component of missile velocity

6-26. What determines the location of the center of gravity of an object?

1. The orientation of the object with respect to the Earth
2. The resultant of all the weight forces acting on the object
3. The distance of the object from the center of the Earth
4. The position of the object measured with respect to the Earth's surface

6-27. A pendulum located on the Earth's surface will align itself to the local vertical rather than the true vertical primarily because of the

1. Earth's angular motion
2. Earth's spherical shape
3. uniform density of the Earth's mass
4. coincidence between the Earth's center of gravity and its geometric center

6-28. How does the centrifugal force caused by Earth's rotation vary with latitude?

1. The force is greatest where the Earth's angular velocity is minimum
2. The force is greatest where the Earth's angular velocity is maximum
3. The force is zero at the poles and greatest at 45-degree latitude
4. The force is zero at the equator and greatest at 45-degree latitude

6-29. A pendulum located at the axis of the Earth's rotation would sense

1. maximum gravity and maximum centrifugal force
2. minimum gravity and minimum centrifugal force
3. maximum centrifugal force and minimum gravity
4. minimum centrifugal force and maximum gravity

6-30. Which reference is used to align the inertial devices in the missile guidance system?

1. The local verticals along the flight path
2. The true vertical along the flight path
3. The local vertical at the launch point
4. The true vertical at the launch point

*Learning Objective: Identify the properties, physical arrangement, and applications of gyroscopes.*

6-31. The Earth and a gyroscope are common in that they

1. have a spin axis which tends to change direction in space
2. are a spinning mass with limited rotational freedom of their spin axis
3. are a spinning mass with unlimited rotational freedom of their spin axis
4. display unreliable stability

6-32. The spin axis of a gyroscope tends to remain fixed in a given direction if the rotor

1. has a large diameter
2. spins at high speed
3. is perpendicular to the Earth's surface
4. is parallel to the Earth's surface

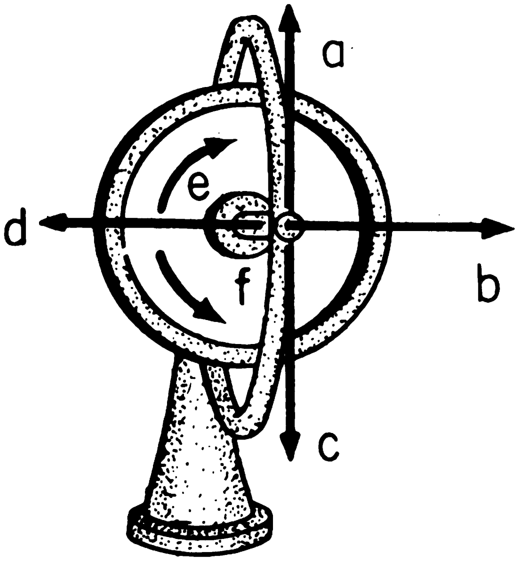

Figure 6-A.--Balanced gyro top.

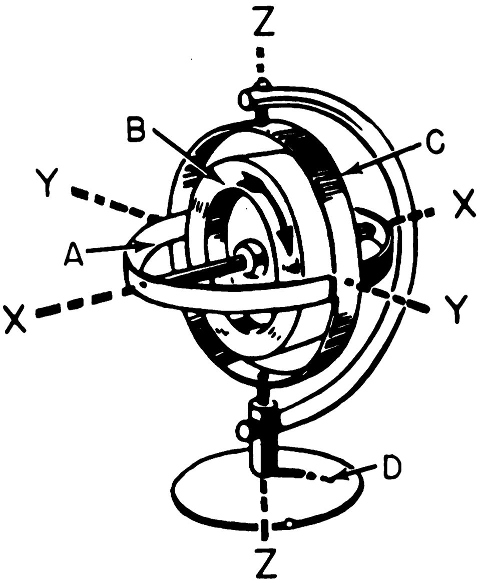

Figure 6-B.--Universally mounted gyro.

6-33. With the gyro in figure 6-A spinning in direction E, a force exerted in direction A would cause the gyro axis to move in direction

1. a
2. b
3. c
4. d

6-34. With the gyro in figure 6-A spinning in direction F, a force exerted in direction C would cause the gyro axis to move in direction

1. a
2. b
3. c
4. d

6-35. The spin axis of the gyro wheel in figure 6-B is represented by

1. X-X
2. Y-Y
3. Z-Z
4. X-X and Y-Y

6-36. A device that permits a body to incline freely in any direction and maintain that angle when its support is tipped is known as a

1. gyro
2. wheel
3. gimbal
4. pendulum

6-37. Where must the center of gravity be located on the gyro in figure 6-B?

1. Along the X-X axis
2. Along the Z-Z axis
3. At the intersection of Y-Y axis and the support frame
4. At the intersection of X-X, Y-Y, Z-Z axes

6-38. What factors determine the amount of rigidity of a gyro?

1. Rotor speed, distribution of weight, and rotor size
2. Rotor size, rotor weight, and rotor speed
3. Distribution of weight, rotor weight, and rotor size
4. Rotor weight, distribution of weight, and rotor speed

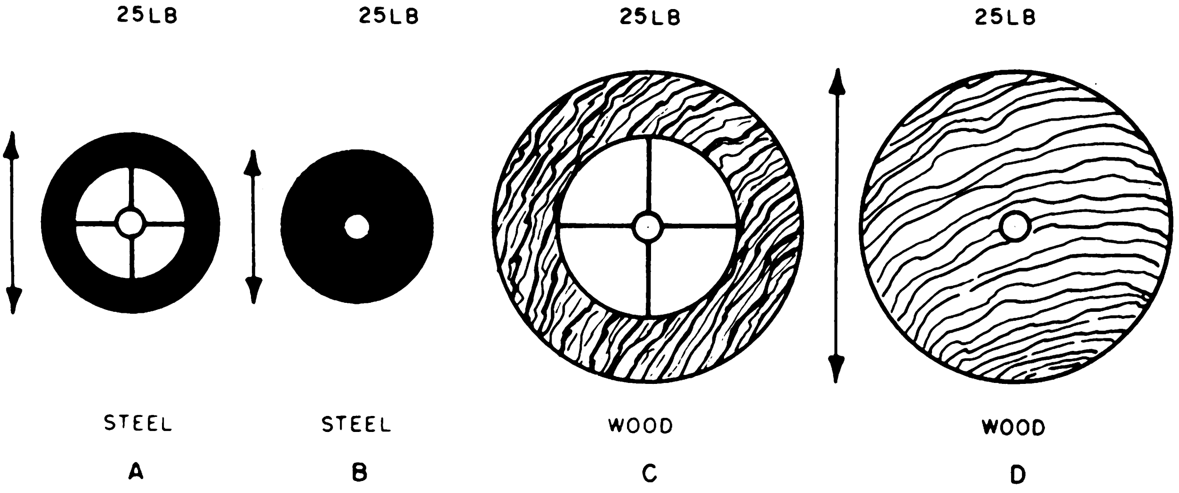

Figure 6-C.--Gyro rigidity.

6-39. Assuming that the gyro rotors shown in figure 6-C are all spinning at the same rate, which alternative lists them in order of decreasing rigidity?

1. B, C, D, A
2. C, D, B, A
3. C, D, A, B
4. D, C, A, B

6-40. Which gyro rotor in figure 6-C has the greatest moment of inertia?

1. A
2. B
3. C
4. D

6-41. A force applied to an operating gyro that tends to change the direction of its spin axis will cause the spin axis to be displaced in a direction which

1. is at some random angle to the applied force
2. is at right angles to the applied force
3. opposes the applied force
4. aids the applied force

6-42. With the gyro wheel in figure 6-D not spinning, a downward force exerted at point A will cause movement in direction

1. m
2. n
3. o
4. p

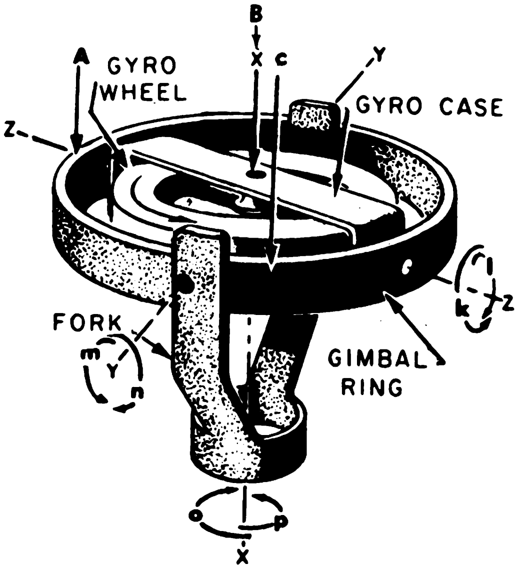

Figure 6-D.--Gimbal-mounted gyro.

6-43. With the wheel in figure 6-D spinning in the direction shown, a downward force exerted at point A will cause the gyro to precess in direction

1. k
2. l
3. m
4. n

6-44. With the gyro wheel in figure 6-D spinning in the direction shown, a downward force exerted at point C will cause the gyro to precess in a direction which is a combination of

1. k and m
2. k and n
3. l and m
4. l and n

6-45. With the gyro wheel in figure 6-D spinning in the direction shown and a torque applied in direction l to the Z-Z axis, in what direction, if any, will the gyro precess?

1. k
2. m
3. o
4. None

6-46. With the gyro wheel in figure 6-D spinning in the direction shown and a downward force exerted at point B, in which direction, if any, will the gyro precess?

1. k
2. m
3. o
4. None

6-47. The rate of precession of a gyroscope is governed by the same factors as those that determine

1. rigidity
2. translation
3. stabilization
4. directional error

---

To answer items 6-48 through 6-50, select from column B the indication provided by the gyroscopic vector listed in column A.

A. VECTOR

6-48. Torque vector

6-49. Precession vector

6-50. Spin vector

B. INDICATION

1. Gimbal rotational rate
2. Results of applied torque
3. Motion which changes the direction of the rotor axis
4. Velocity of the gyro rotor

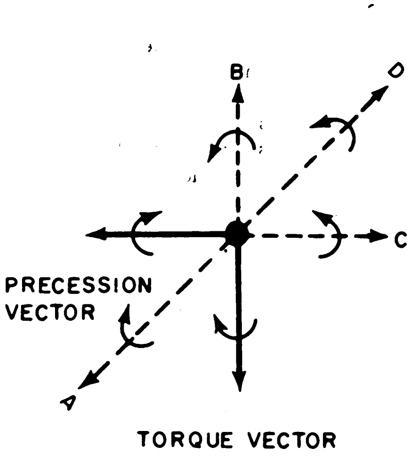

Figure 6-E.--Gyro vectors.

6-51. The solid lines in figure 6-E represent the direction and rotary motions of the precession and torque vectors of a gyro. Using the three-finger and right-hand rule, select the dotted line which represents the direction and rotary motion of the spin vector.

1. A
2. B
3. C
4. D

6-52. The right-hand rule for gyroscopes may be used in determining the direction of which of the following?

1. Spin
2. Torque
3. Precession
4. All of the above

6-53. In what total number of planes does a universally mounted gyro have freedom of movement?

1. One
2. Two
3. Three
4. Four

6-54. Assume that a spinning gyro is placed on the Equator with one end of its axis pointing north. In what direction will this end be pointing after 12 hours?

1. North
2. South
3. East
4. West

6-55. If you view the Earth from above the North Pole, what is the rate and direction of the Earth's rotation?

1. 15 degrees an hour clockwise
2. 30 degrees an hour clockwise
3. 15 degrees an hour counterclockwise
4. 30 degrees an hour counterclockwise

6-56. Assume that a spinning gyro is placed on the Equator with one end of its spin axis pointing east. In what direction will this end be pointing after 12 hours?

1. North
2. South
3. East
4. West

6-57. Gyroscopic drift is produced by which of the following?

1. Inertia of the spin axis
2. Symmetrical bearing friction
3. Imbalance due to excessive operating speeds
4. All of the above effects

6-58. Which of the following is/are (a) purpose(s) of a gyro-erection system?

1. To establish the desired direction of the spin axis
2. To correct for the effect of apparent drift
3. To correct for the effect of mechanical drift
4. All of the above

6-59. The primary difference between a rate gyro and a free gyro is that the rate gyro precesses

1. at a set rate
2. freely in two degrees of freedom
3. without activating the erecting system
4. under restraint in one degree of freedom

6-60. What is the purpose of the springs in figure 7-17 of the textbook?

1. To provide precessional force to the gyro wheel
2. To measure the gyro's rate of precession
3. To measure the amount of precession of the gyro
4. To provide a restraining force to the precession of the gyro wheel

6-61. When does a rate-of-turn gyro that is precessed re-erect itself?

1. When the movement of its mounting is stopped
2. When the gyro case is rotated at a constant speed
3. When its case is restored to its original position
4. When the rate of movement of its mounting is decreased

6-62. The restraint used in most floated rate gyro units is a

1. fluid
2. spring
3. lever arm
4. torsion bar

6-63. What is the purpose of floating the inner gimbal of a hermetically sealed integrating gyro in a fluid?

1. To provide a dynamic balance
2. To lubricate the moving parts
3. To reduce gimbal bearing friction
4. To transmit the applied force to the gyro

6-64. In figure 7-21 of your textbook, how is the stable platform aligned?

1. By establishing the true vertical reference axis
2. By keeping the platform stationary with respect to the vehicle
3. By driving the platform in the opposite direction that the vehicle rotated
4. By driving the platform in the same direction as the vehicle rotated

6-65. One of the factors that provides a relationship between the actual flight path and the prescribed flight path is the

1. use of velocity as a common unit of measure
2. measurement of the displacement of the missile from the launch point
3. use of the true vertical as a common reference axis
4. use of two inertial coordinate systems in the missile

6-66. In the gimbal system shown in figure 7-22 of your textbook, which of the following gimbal(s) has/have three degrees of freedom?

1. Inner
2. Middle
3. Outer
4. Each of the above

6-67. The missile flight attitude with respect to the inertial coordinate system is determined by measuring the

1. velocity of the missile
2. acceleration of the missile
3. angular displacement of the gimbal axes
4. linear displacement of the gimbal axes

6-68. What type of device is used to measure the linear motions of the missile?

1. Accelerometer
2. Integrating gyro
3. Rate-of-turn gyro
4. Inertial reference integrating gyro

# Assignment 7

**Inertial Devices (continued); Polaris Fleet Ballistic Missile Problem**

Textbook Assignment: Fire Control Technician (B) 3&2, Vol. 1, NAVEDTRA 10211-B1; pages 120-126

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*Learning Objective: Recognize the purpose and principles of operation of accelerometers using the correct terminology.*

7-1. An object suspended in a system that is undergoing acceleration will move

1. in the direction of the acceleration
2. opposite to the direction of the acceleration
3. at right angles to the direction of the acceleration
4. in a direction that depends on the amount of acceleration

7-2. The basic accelerometer responds to forces oriented

1. at right angles to the sensitive axis
2. about its sensitive axis
3. along the sensitive axis
4. in any direction

7-3. The function of the fluid normally found in an accelerometer is to

1. prevent oscillation of the mass
2. lubricate the internal parts
3. provide cooling for the inertial device
4. transmit the accelerating force from the case to the mass

7-4. Refer to figure 7-24 of the textbook. In what direction does the rotational axis of the mass lie in reference to the gimbal axis?

1. Parallel to the inner and perpendicular to the outer gimbal axis
2. Perpendicular to the inner and parallel to the outer gimbal axis
3. Parallel to the inner and outer gimbal axis
4. Perpendicular to the inner and outer gimbal axis

7-5. To what part of the pendulous integrating gyro accelerometer (PIGA) is the pickoff attached to measure the rate of rotation of the gimbal?

1. Pivot axis
2. Rotor spin axis
3. Inner gimbal axis
4. Outer gimbal axis

7-6. The purpose of the torque system associated with the accelerometer gimbals is to

1. provide a dampening effect
2. prevent accelerometer precession
3. prevent loss of sensing capabilities
4. provide a method of applying torque to the inner gimbal

7-7. In the incremental coder, how are disks "A" and "B" mounted to measure the amount and direction of the gimbal rotation?

1. Both disks, "A" and "B," are fixed to the PIGA case.
2. Both disks, "A" and "B," are attached to the movable output shaft.
3. Disk "A" is fixed to the PIGA case, disk "B" is attached to the movable output shaft.
4. Disk "A" is attached to the movable output shaft, disk "B" is fixed to the PIGA case.

7-8. The total rotation of the gimbal output shaft of a PIGA is proportional to the

1. applied torque
2. precession rate
3. amount of pendulum deflection
4. vehicle's instantaneous velocity

7-9. The type of microsyn known as a Ducosyn is identified by a

1. precision potentiometer
2. closed loop
3. double rotor
4. double stator

7-10. The output signal from a pulse integrating pendulous accelerometer (PIPA) is proportional to the

1. sum of the times required for the negative and positive excursions of the pendulum
2. resultant of the times required for the negative and positive excursions of the pendulum
3. ratio between the times required for the negative and positive excursions of the pendulum
4. product of the times required for the negative and positive excursions of the pendulum

THE REMAINDER OF ASSIGNMENT 7 (PAGES 45 THROUGH 48) HAS BEEN DELETED FROM THIS EDITION.

ASSIGNMENTS 8, 9, 10, 11, 12, AND 13 (PAGES 50 THROUGH 82) HAVE BEEN DELETED FROM THIS EDITION.

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RANK/RATE ________ SOC. SEC. NO. ______________ DESIGNATOR ________ ASSIGNMENT NO. ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ______________ DATE MAILED ________

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**PRINT OR TYPE**

Fire Control Technician B 3 & 2, VOL. 1
NAVEDTRA 10211-B1, VOL. 1

**NAME** ______________________________ **ADDRESS** ______________________________
Last First Middle Street/Ship/Unit/Division, etc.

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City or FPO State Zip

**RANK/RATE** ________ **SOC. SEC. NO.** ________________ **DESIGNATOR** ________ **ASSIGNMENT NO.** ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ________________ DATE MAILED ________

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**PRINT OR TYPE**

Fire Control Technician B 3 & 2, VOL.
NAVEDTRA 10211-B1, VOL. 1

NAME ______________________ ADDRESS ______________________
Last First Middle Street/Ship/Unit/Division, etc.

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City or FPO State

RANK/RATE ________ SOC. SEC. NO. ______________________ DESIGNATOR ________ ASSIGNMENT NO. ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ______________ DATE MAILED ________

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**PRINT OR TYPE**

Fire Control Technician B 3 & 2, VOL. 1
NAVEDTRA 10211-B1, VOL. 1

NAME ______________________________ ADDRESS ______________________________
Last First Middle Street/Ship/Unit/Division, etc.

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City or FPO State Zip

RANK/RATE ________ SOC. SEC. NO. ________________ DESIGNATOR ________ ASSIGNMENT NO. ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ________________ DATE MAILED ________

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| 1 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 26 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 51 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 2 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 27 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 52 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 3 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 28 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 53 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 4 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 29 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 54 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 5 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 30 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 55 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 6 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 31 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 56 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 7 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 32 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 57 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 8 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 33 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 58 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 9 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 34 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 59 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 10 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 35 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 60 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 11 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 36 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 61 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 12 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 37 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 62 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 13 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 38 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 63 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 14 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 39 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 64 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 15 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 40 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 65 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 16 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 41 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 66 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 17 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 42 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 67 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 18 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 43 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 68 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 19 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 44 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 69 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 20 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 45 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 70 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 21 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 46 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 71 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 22 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 47 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 72 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 23 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 48 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 73 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
| 24 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 49 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ | 74 | ☐ | ☐ | ☐ | ☐ | _ _ _ _ _ |
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**PRINT OR TYPE**

Fire Control Technician B 3 & 2, VOL. 1
NAVEDTRA 10211-B1, VOL. 1

NAME ________________________________ ADDRESS ________________________________
Last First Middle Street/Ship/Unit/Division, etc.

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City or FPO State Zip

RANK/RATE ________ SOC. SEC. NO. ________________________ DESIGNATOR ________ ASSIGNMENT NO. ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ________________ DATE MAILED ________

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Fire control technician B 3 & 2.

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